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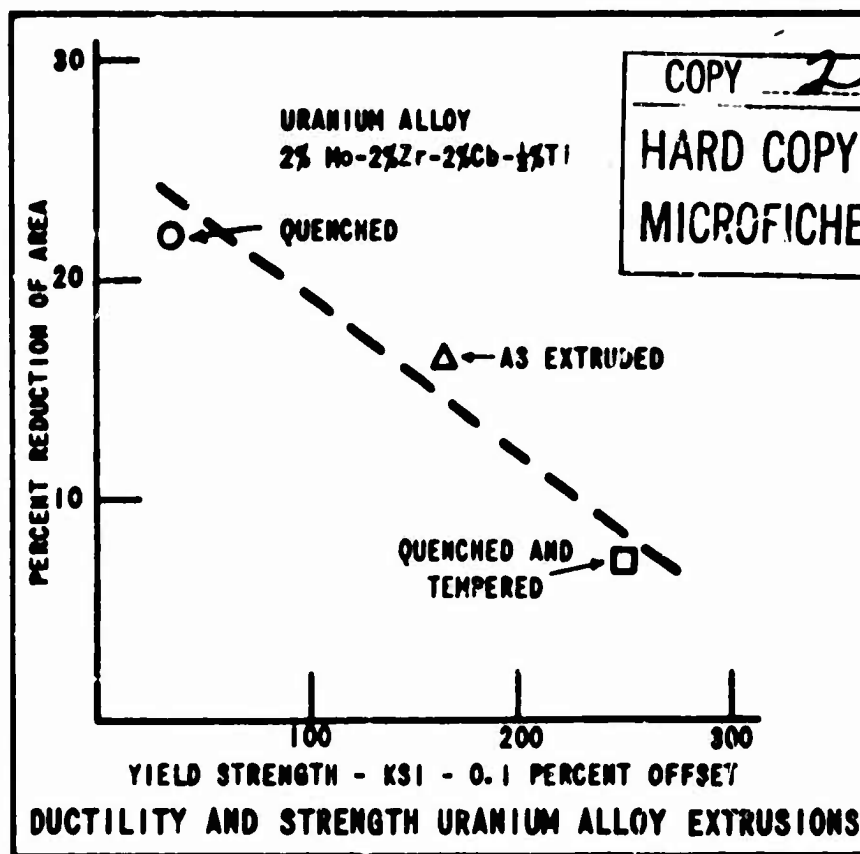
WATERTOWN ARSENAL
WATERTOWN, MASS.

U. S. ARMY

Monograph Series

NUMBER 55

URANIUM
PROPERTIES · PROCESSES · CONTROLS

URANIUM ALLOY
2% Mo-2½Zr-2%Cb-½%Ti

QUENCHED

△ ← AS EXTRUDED

QUENCHED AND
TEMPERED

PERCENT REDUCTION OF AREA

30

20

10

100   200   300

YIELD STRENGTH - KSI - 0.1 PERCENT OFFSET

DUCTILITY AND STRENGTH URANIUM ALLOY EXTRUSIONS

OCTOBER 1962
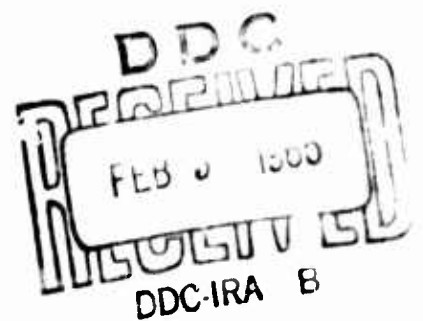
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FOREWORD

This document sets out a short history of the development of uranium as an engineering material and includes the current practices of Watertown Arsenal regarding materials processing, accountability, and health and safety. During the early development of uranium as a nuclear fuel, interest was directed toward utilizing the metal as an engineering material. This interest has led to the development of several high-strength, high-density uranium alloys for application to Army materiel.

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CHAPTER I

INTRODUCTION

Purpose

The purpose of this document is to present the multi-varied experiences of Watertown Arsenal and its Laboratories regarding the production, fabrication, handling, utilization, control, and safety considerations of natural or depleted uranium.

Background

Massive uranium is a product of the nuclear age. Prior to the development of the atomic bomb, it was a laboratory curiosity. However, with the advent of atomic bombs, nuclear reactors, and other atomic devices, techniques were found to produce uranium in production quantities.

Uranium, in its natural state, is only mildly radioactive and also will not support a nuclear chain reaction. It has to be enriched in one or more of its isotopes for use in reactors and atomic weapons. This document will not discuss highly enriched uranium, but rather will treat only the utilization of natural or depleted uranium (i.e., uranium from which the fissionable isotope has been separated).

Because of its several unique properties, uranium has been found to be particularly suitable for certain applications such as spotting rounds for ordnance and as counterweights in Army aircraft. Applications are based primarily on uranium's high density; it is almost two and a half times denser than steel and more than one and a half times denser than lead. In addition, it can be readily alloyed, worked, and machined. Heat treatment yields products of adequate toughness and strength. When proper and easily applied safety precautions are taken, there are very few health hazards. Corrosion is a problem, but several methods are available to overcome it. Accountability of United States Atomic Energy Commission licensed uranium is a necessity, but it is no problem when good bookkeeping practice is employed.

CHAPTER II

PROPERTIES OF URANIUM

Section 1 - General

General Properties

Uranium is a typical metal. It is opaque, reasonably malleable, and a moderately good conductor of heat and electricity. A freshly prepared, clean surface of the metal exhibits a silvery-white metallic luster, but the surface soon starts oxidizing and the surface color changes from silver-white to amber, dark brown, and finally to black with a uranium dioxide (UO_2) coating. It has a high density, about 19 grams per cubic centimeter (0.686 pounds per cubic inch) in wrought material; this makes it almost as dense as gold and about 1.7 times denser than lead. There are three allotropic crystalline modifications of uranium called the alpha (orthorhombic) phase, the beta (tetragonal) phase, and the gamma (body-centered cubic) phase. The mechanical properties are quite structure sensitive. One of the most unusual eccentricities of uranium is an exaggerated lengthening and twisting of a cast rod, fabricated in the alpha temperature range, upon being alternately heated and cooled. To prevent this unidirectional growth, it is necessary to avoid preferred orientation of the grains; this can be accomplished by annealing the rod in the beta phase temperature range, thereby causing a random distribution of the grains. In other words, it is essential for the fabricator to understand the behavior of uranium in its three modifications to formulate appropriate working and annealing cycles.

Section 2 - Radiation Characteristics of Uranium

General

Natural uranium contains three different kinds of atoms (isotopes[*]) which are almost identical in their physical and chemical properties; they differ markedly in their nuclear properties, that is, those that depend upon the makeup of the central nucleus of the atom. Table I shows how these three isotopes differ.

The first stages of the uranium isotope decay series are given in Table II. The final end products of each of these series is a stable isotope of lead (Pb). If the starting material is pure, natural, or depleted uranium, the only decay products that are likely to be encountered are Th^{234} (UX_1) and Pa^{234} (UX_2) which are emitters of energetic beta

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[*]An isotope is one of several kinds of a single element having the same number of protons in the nuclei but different numbers of neutrons; hence, different atomic mass numbers.

TABLE I

ISOTOPIC COMPOSITION OF NATURAL URANIUM

Isotope	Abundance (percent)	Nuclear Composition*		Half Life (years)
		No. of protons	No. of neutrons	
U^{238}	99.3	92	146	4.5 billion
U^{235}	0.7	92	143	700 million
U^{234}	0.005	92	142	240 thousand

*The number of protons (or nuclear charge) plus the number of neutrons equals the atomic mass number, i.e., U^{235}, and U^{234}.

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TABLE II

RADIOACTIVITY DECAY SERIES OF URANIUM ISOTOPES

$U^{238} \xrightarrow[4.5 \times 10^9 y*]{\alpha, \beta} \quad Th^{234} \xrightarrow[24.1d]{\beta, \gamma} \quad Pa^{234} \xrightarrow[1.175m]{\beta, \gamma} \quad U^{234} \xrightarrow[2.5 \times 10^5 y]{\alpha, \gamma}$

$U^{235} \xrightarrow[7 \times 10^8 y]{\alpha, \gamma} \quad Th^{231} \xrightarrow[25.6hr]{\beta, \gamma} \quad Pa^{231} \xrightarrow[3.4 \times 10^4 y]{\beta, \gamma} \quad Ac^{227} \xrightarrow[21.6y]{\alpha, \gamma}$

$U^{234} \xrightarrow[2.5 \times 10^5 y]{\alpha, \gamma} \quad Th^{230} \xrightarrow[8.0 \times 10^4 y]{\alpha, \gamma} \quad Ra^{226} \xrightarrow[1622y]{\alpha, \gamma} \quad Rn^{222} \xrightarrow[3.82d]{\alpha, \gamma}$
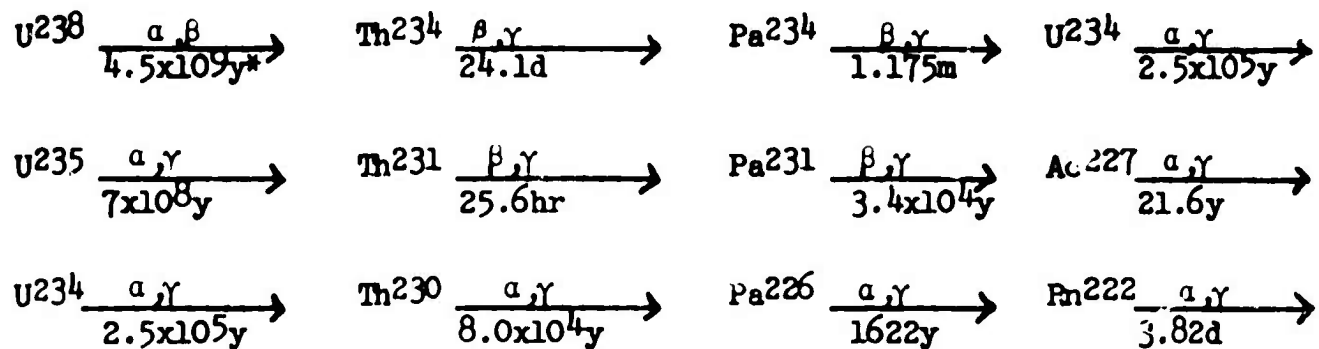
*y = years
d = days
m = minutes
hr = hours

and gamma radiation, the presence of which is readily observed by means of an ordinary survey meter.

The number of protons (the atomic number) for each isotope is the same. The number of neutrons varies, and as is shown by the half-life figure, the stabilities of the three isotopic species are quite different. The half-life is the elapsed time for half of the atoms in a sample to transform into atoms of another kind of chemical element and to release energy. The three isotopes also differ in another important property, namely the ability to fission when bombarded by neutrons. Although the most abundant isotope, U^{238} will fission, U^{238} alone cannot be used to support the multiplying chain reaction required in a nuclear weapon or a nuclear reactor. U^{235}, on the other hand, is easily caused to fission and is the basis for the entire atomic energy program.

Radioactivity is a process of spontaneous transmutation exhibited by many elements. In this process, several kinds of nuclear particles and energetic gamma- or x-rays are emitted. The so-called daughter elements may also be radioactive and the process may continue through several steps until a stable element is formed. As indicated by their half-lives (Table II) must of the uranium isotopes are only mildly radioactive; i.e., they have long half-lives and emit their energy of decay over a long period of time. Uranium itself is not a serious radiological hazard unless it is ingested into the body. Some of the daughter products are, however, highly radioactive and may present genuine hazards. Once the uranium has been separated from the ore and converted into the pure metal, in the form of barstock, the radioactivity no longer presents a serious health hazard. Depleted uranium metal nevertheless is almost as radio-active as pure natural uranium element. In a very few months both depleted and natural uranium contain daughter products from the decay of U^{238} that can readily be detected by sensitive instruments. These do not present a hazard until they are concentrated, and this cannot happen until the metal is melted. The slag of a uranium melt may contain the separated decay products and be hazardous unless precautions are observed.

Purified uranium metal that has been allowed to stand around for about six months is now in secular equilibrium with the only important daughters, Th^{234} and Pa^{234}, and the radioactivities that are observed are alpha-particle (a) emission by both U^{238} and U^{234} and the beta-particle (β) emissions of both Th^{234} and Pa^{234} and their accompanying weak gamma (γ) rays. The strongest activity escaping from the surface is the 2.32 Mev beta-particle of Pa^{234}. The specific disintegration rate of six-month or older metallic uranium is 1500 alpha particles and 1500 beta particles per milligram of metal per minute. In terms of surface dose rate this corresponds to 240 millirads per hour which is considerably above the accepted tolerance dose rate for prolonged exposure (See Chapter V). Because of the low penetrating power of both alpha and beta particles, this radioactivity does not present a serious hazard and it is easily avoided.

Classification

Natural uranium (which contains 0.7 percent U^{235}) or concentrated U^{235}, tha' has been separated from U^{238}, is required to make a nuclear chain reaction occur. The separation of U^{235} from the more abundant U^{238} has been accomplished at the plants of the U. S. Atomic Energy Commission and elsewhere to supp rt the world-wide atomic energy program. U^{234} occurs to too small an extent to make its use possible. The separated isotopes have been given code names to identify and distinguish them from the natural element which is often referred to as TUBALLOY.

ORALLOY is uranium material that has a higher U^{235} content than the natural element. The degree of enrichment is represented by a percentage figure, indicating the proportion of U^{235}. So-called highly enriched ORALLOY, used as fuel in many nuclear reactors contains in excess of 93.5 percent U^{235}. A bare sphere of this material that weighs only 107.8 pounds is a "critical mass" in that it will fission spontaneously with a release of a tremendous amount of energy. If immersed in water which serves as a moderator and enhances the tendency to fission, the weight of the sphere is reduced to about 40 pounds; and if the ORALLOY is subdivided to an optimum size and surrounded by water, only 1.76 pounds are needed to exceed a critical mass. Great care must be exercised in handling ORALLOY to avoid a configuration that produces a critical mass. ORALLOY also contains up to 2 percent of U^{234}, that is separated with U^{235} from the natural uranium.

DEPLETALLOY or D-38, on the other hand, is the uranium residue after the U^{235} has been extracted; it is U^{238} that contains much less than the original 0.7 percent of U^{235}. Depleted uranium or DEPLETALLOY is a by-product of the atomic energy program. Because the cost of separating the uranium isotopes is charged primarily to the ORALLOY, depleted uranium may be obtained for little more than the cost of recovering it from the plant waste material, and it comes on the market as the least expensive, high-density material. It is finding industrial and military applications.

Section 3 - Physical and Mechanical Properties of Uranium

General

Several pertinent physical and mechanical properties of pure uranium metal are given in Tables III and IV. Those of both ORALLOY and DEPLET-ALLOY are essentially identical with those of the natural element.

Physical Properties

The physical properties of pure uranium metal are given in Table III.

Mechanical Properties

The mechanical properties of pure (alpha phase, unalloyed) uranium are given in Table IV.

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TABLE III

PHYSICAL PROPERTIES OF PURE URANIUM *

Melting Point   1132 ± 0.8°C (2070.4 ± 1.5°F)

Boiling Point   3818°C (6904°F)

Crystal structure

     alpha phase - room temp. to 662°C (1225°F) orthorhombic

     beta phase - 662 to 774°C (1225 to 1420°F), tetragonal

     gamma phase - 774 to 1132°C (1420 to 2070°F), body centered cubic

Density

     alpha phase - 19.07 gm/cc at 25°C (0.688 lb/cu in at 77°F)

     beta phase - 18.13 gm/cc at 700°C (0.654 lb/cu in at 1328°F)

     gamma phase - 17.91 gm/cc at 800°C (0.653 lb/cu in at 1481°F)

Coefficient of Thermal Expansion   11.37 (30° to 1,200°F)

    $(in./in./°F \times 10^{-6})$

Thermal Conductivity   0.071 (cal/cm/sec/°C) at room temperature

                  0.112 at 815°C (1500°F)

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*For references see page 95

TABLE IV

MECHANICAL PROPERTIES OF ALPHA PHASE, UNALLOYED URANIUM

Property	TEMPERATURE		
	Room Temp.	570°F(299°C)	930°F(499°F)
Ultimate tensile strength, ksi	56 - 96	35	11
Yield strength (0.2% offset) ksi	24 - 38	18	5 - 7
Elongation (total) %	6 - 12	33 - 49	44 - 61
Modulus of Elasticity (10^6 psi)	22 - 29	16	14
Hardness (VHN)	255	104	46

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Section 4 - Chemical Properties

General

Metallic uranium is an active metal falling in the electrochemical series between beryllium and manganese. It is much more reactive in a finely divided condition than when present as massive barstock. It reacts with a wide variety of elements including oxygen, hydrogen, fluorine, bromine, chlorine, carbon, sulfur, and nitrogen. It also reacts with numerous common compound chemicals like water, hydrogen chloride, nitric acid, sulfuric acid, phosphoric acid, perchloric acid, organic acids, ammonia, alkaline peroxide solutions, silver and copper salts and silica. Because of its reactions with air and water, particularly, it must be protected from atmospheric corrosion, usually by plating or by canning it in another metal like aluminum.

One of the more interesting reactions is the formation of the hydride. If uranium turnings or lumps are exposed to hydrogen at a temperature above 250°C (482°F), a gray to black powder, UH_3, readily forms. Both the hydride and the metal powder are pyrophoric and hazardous. If it is heated to higher temperatures in a vacuum or inert atmosphere, it decomposes to finely-divided, metallic uranium and hydrogen. This process is used to convert solid barstock to uranium powder for various chemical or metallurgical purposes. Finely divided uranium is an excellent gettering or scavengering material to remove impurities from inert gas atmospheres.

Dilute nitric acid will remove the black tarnish from the surface of uranium. Uranium turnings, on the other hand, may react with explosive violence to a more concentrated nitric acid. When more than 5 or 6 grams of turnings are to be dissolved the metal should be added little by little to the acid rather than vice versa. The product of the reaction is uranyl nitrate, $UO_2(NO_3)_2.6H_2O$.

Uranium can form compounds in various states of oxidation as represented by its oxides: UO, UO_2, U_3O_8, and UO_3. It also forms an orange peroxide, $UO_4.2H_2O$.

Pyrophoricity

Freshly-cleaned uranium surfaces slowly oxidize at room temperature, and they assume various colors as follows:

Original condition	Shiny, like platinum
After one hour	Very thin yellow film
After two hours	Yellow
After one day	Golden
After two days	Iridescent, steel blue to purple
After three or four days	Dark purple, finally black

Turnings burn in air without a flame when ignited; the metal merely glows as the oxidation progresses rapidly along the length of the turning.

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The black oxide, U_3O_8, if formed, and it partially flakes off. When relatively thick turnings are ignited, a core of unburned metal is often left inside. The oxide formed under such conditions contains as much as a half percent of nitrogen. Complete oxidation is ensured only after the reaction products are ignited in a muffle furnace at 700 to 1000°C (1292 to 1832°F) or over a flame for one hour, and the oxide formed is nitrogen free. Massive lumps of uranium are slowly oxidized at 500 to 700°C (932 to 1292°F).

Powdered uranium is pyrophoric, glowing bright orange while burning. A study conducted at the Argonne National Laboratory has shown that there is a wide variation in the ignition behavior of uranium specimens from various sources, and a strong sensitivity to the metallurgical history of specimens from any single source. With respect to beta-quenched uranium, as-cast uranium exhibited significantly higher oxidation rates and lower ignition temperatures than other forms. This being the case, precautions must be taken to avoid spontaneous ignition of turnings and other scrap. If feasible, all scrap should be burned as soon as possible after being generated, to convert it to U_3O_8, the stable oxide. Prior to burning, scrap may safely be maintained in a dry condition, under a high flash point oil, or under water.

Section 5 - Alloying of Uranium

General

Pure uranium, like many pure metals, is a relatively soft, ductile, low-strength material. In addition, the pure material has extremely poor corrosion resistance. It is possible, however, to improve both the physical properties and the corrosion resistance by alloying. Many of these alloys can be further improved by hot working, heat treatment, or a combination of both. Typical of these alloys is the 8%Mo-1/2%Ti alloy, which combines good corrosion resistance with sufficient strength and ductility to make it a useful structural material for application where a high-density material is desired.

Alloying Characteristics

The alloying characteristics of uranium can be grouped on the basis of similarities evident in the phase diagram.[2] One group consists of the elements that form intermetallic compounds with uranium. Alloys of uranium with either aluminum, beryllium or carbon are of this type. Elements which do not form compounds and have limited terminal solubility make up another group. Alloys of this type include U-Cr, U-Ta, U-W and U-V. Elements which do not form compounds but do form extensive solid solutions with uranium can be classified into a third group that includes U-Mo, U-Ti[*], and U-Zr. Equilibrium diagrams are available for a large

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[*]The alloy phase U_2Ti has also been found in this system.

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number of uranium alloys[3]. The isothermal transformation kinetics of a limited number of alloys have also been determined. Reference is made to these data in establishing heat-treat schedules and investigating new alloy compositions.

Section 6 - Heat Treatment

General

One of the chief aims of alloying and heat-treating uranium is to achieve a more stable structure. Another important aim is to produce a stronger and more corrosion-resistant material. Growth occurring in untreated uranium during thermal cycling or as a result of irradiation causes physical damage to the metal. By eliminating preferred orientation in the crystal structure it is possible to prevent such harmful growth. This can be accomplished by working the uranium in the alpha region followed by annealing in the beta region.

The isothermal transformation kinetics of a limited number of alloys have also been determined. Reference is made to these data in establishing heat-treat schedules and investigating new alloy compositions.

The U-8%Mo-0.50%Ti and the U-10.5%Mo are high-strength, high-density alloys. The heat treatments applied to the different classes of alloys vary depending on the results sought. Grain refinement is produced in beta stabilized U-Cr alloys by a quench and temper treatment at 500°C (932°F). A wide range of properties is achieved by aging supersaturated alpha-phase alloys. Gamma phase alloys of U-Mo and U-Cb often require a homogenizing treatment as do the alloys based on the intermetallic compound structure.

Table V lists the mechanical properties of a number of the more common uranium alloys investigated. Such alloys are normally melted in induction or arc furnaces under inert atmospheres or vacuum. Crucibles and molds are prepared from refractory oxide or oxide-coated graphite. Castings are heated in protective atmospheres or salts for subsequent processing.

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TABLE V

MECHANICAL PROPERTIES OF SEVERAL URANIUM ALLOYS

Alloy Composition	Condition	Yield Strength 0.1% ksi	0.2% ksi	T. S. ksi	Elon. (%)	R. A. (%)	Youngs Modulus (psix10⁶)	Charpy V-Notch at -40°F (ft-lb)	Density (g/cc)
U-9%Al[a]	As rolled	---	19.9	27.9	---	6.7	---	---	---
U-2%Mo[a]	Quench from 750°C (1382°F)	---	---	168.8	4.0	15.9	---	---	---
U-8.0%Mo-0.50%Ti[b]		135	139	139	15.0	50.0	---	4.0	17.2
U-10.5%Mo[b]	As extruded	138	---	139	10.0	23.0	---	3.2	17.2
U-Unalloyed[b]	Vacuum Annealed Rolled Stock	20	---	42	10.0	13	---	10.0	---
U-Alloyed[b,c]	As extruded	164	---	221.0	8.0	16	---	6.8	17.2
	As quenched	35	---	119.0	17.0	22	---	16.0	---
	Quenched and Aged	248	---	264	3.0	17.2	---	2.7	---

[a] Reactor Handbook, Interscience Pub. 1960

[b] Watertown Arsenal Laboratories Determination

[c] 2%Mo, 2%Cb, 2%Zr, 0.5%Ti

CHAPTER III

FABRICATION AND FINISHING OF URANIUM

Section 1 - General

General

The application of uranium alloys has arisen largely out of a special need for high density components. For example, in some ballistic projectiles, high density is a fundamental requirement for the attainment of a suitable ballistic coefficient, and thus uranium alloys are useful as spotting rounds. Another possible application is in armor plate which is required to perform the dual function of resisting both ballistic projectiles and gamma radiation. In this case, the high attenuation for gamma radiation by uranium might be utilized. A third possible application is in high density armor piercing projectiles. Thus the ever increasing supply of depleted uranium is of general interest to the Army.

Property Requirements for Applications

The previously mentioned applications have general mechanical property requirements as follows: spotting rounds - high density and relatively high strength together with adequate ductility and toughness; armor plate - very high toughness together with adequate strength; armor piercing projectiles - very high hardness and strength together with adequate toughness. Thus the alloys employed must have the capability to respond to known methods of metallurgical engineering by which a given set of mechanical properties may be attained with reasonable accuracy and facility. In particular it is desirable that they respond to thermal treatment to the extent that it is possible to obtain the most formable or fabricable condition for manufacture, after which optimum properties (e.g. strength, ductility, hardness, and/or toughness) may be achieved by a final thermal treatment. In addition, a universal requirement is that of corrosion resistance to the normal ambient storage atmosphere.

Processing Procedures for Uranium Alloys

Raw Uranium. The raw uranium used for composing alloys is the so-called dingot (i.e. an ingot produced by direct reduction of uranium tetrafluoride) or derby stock. A derby is a dingot that has been worked, and is usually smaller than a dingot. The purity of the metal obtained in this way is at present, acceptable for alloying. See Table VI for a typical analysis. One of the principal limitations is the carbon content which should not exceed 150ppm for the retention of ductility. The dingot (or derby) as obtained from the primary reduction process, is scalped and further processed as required. This processing may consist of breakdown rolling or extrusion to obtain stock of desired size for re-melting, or the entire dingot (or derby) may be re-melted and alloyed.

TABLE VI

TYPICAL ANALYSIS OF DINGOT URANIUM STOCK

Element	Content(ppm)	Element	Content(ppm)
C	100	Ca	20
Fe	15	Mn	2
Ni	30	Co	4
Cr	2	Cu	15
V	20	Mg	2
Si	30	Li	0.2
Al	10	Be	0.2
H	1	B	0.4
N	10	O	20

Melting of Alloys. Vacuum induction melting is the general technique
employed. The elemental alloy constituents are charged in a magnesia
crucible, induction melted in vacuum, and then poured in vacuum into a
phosphate-bonded zircon mold. An alternate mold-crucible material is
graphite with a refractory coating. The crucible and mold materials
have been chosen by experience as those that least contaminate the melt.
The ingot is then scalped and further processed as required.

Breakdown Operations.

(1) The scalped ingot is generally subjected to mechanical
breakdown by either rolling, forging or extruding. The wrought product
is then the base material from which components are manufactured.

(2) Extrusion is most commonly used as the breakdown step in
producing ordnance components. For this the ingot is sheathed in copper,
either by flame spraying, or conventional canning. In the latter case
the can may or may not be evacuated. Extrusion takes place in the beta
phase at temperatures of the order of 1650°F (900°C). Conventional
graphite lubrication is employed at the die opening. The copper sheathing
serves as an oxidation protector, a parting material between the uranium
and the die wall, and as a lubricant for extrusion. After extrusion, the
copper subsequently is removed from the uranium, after which normal
manufacture of the component may be accomplished.

Review of the Physical and Mechanical Metallurgy of Uranium Alloys

Uranium alloys of general interest to the Department of the Army are
classified in two groups, alpha (orthorhombic structure) and gamma (body
centered cubic structure.) Alloys in the latter group are emphasized
herein since they have shown most over-all promise.

The uranium-molybdenum series of alloys have been of greatest
interest to Ordnance because of their relatively good corrosion resist-
ance, relatively high density, and attractive mechanical properties.
Though alloys of 2 to 12 percent molybdenum content have been considered,
only those containing 8 percent or more have actually been employed.
Molybdenum additions retard the gamma to alpha phase transformation at
ambient temperature. Under normal circumstances alloys containing more
than approximately 7-1/2 percent molybdenum exist as metastable gamma
phase whereas alloys having less than this amount transform to alpha
phase. Columbium as an alloying element also retards the gamma to alpha
transformation. The time-temperature-transformation curves for both
alloying elements are known and may be used as guides for thermal
treatments.

The general metallurgical phenomena which the engineer seeks to
employ for development purposes are solution strengthening, dispersion
strengthening, and martensitic strengthening. As yet, the latter process
has not been detected in uranium alloys. Dispersion strengthening may
take place by partial transformation of gamma to alpha phase or by the

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appearance of a third phase in fine dispersion. Alloying elements associated with the latter are titanium and aluminum or any other which is known to form intermetallic compounds with uranium. Solution strengthening takes place by simple substitutional or interstitial alloying with uranium. Alloying elements associated therewith are molybdenum, columbium, zirconium and vanadium. Developmental efforts have produced several promising alloys, some of which are listed in Tables VII, VIII, IX, and X. These alloys are designated by a reference number and nominal composition. Though in many cases the data are preliminary in nature, it is apparent that some uranium base alloys promise to afford high strength, high hardness materials which also may be heat treated to conditions of lower strength but higher ductility (See Table X.)

Section 2 - Melting and Casting

General

When heated, uranium reacts with many elements and compounds present in normal foundry operations; it is therefore necessary to melt it under either a vacuum or some inert gas and to prevent the molten uranium from contacting surfaces by which it would be contaminated. Another general consideration is that radioactive "daughter" products segregate during melting and casting; they are found mostly in crucible residues and on surfaces of rough castings. This segregation is so pronounced that very real radiation hazards will be found even when melting DEPLETALLOY. It is the basis for the many precautions in the AOD Uranium Operating Procedures.[4]

Melting

Uranium is ordinarily induction melted in vacuum (See Figure 1) and either tilt-poured or bottom-poured directly into the molds. In tilt-pouring, a refractory lining such as magnesium oxide (MgO) is most convenient and will yield metal of high quality. They can be used with graphite molds[5] or ceramic molds[6] with equal effectiveness. Either graphite or MgO linings can be used in standard steel melting furnaces; however, it is desirable to keep the melt temperature below $2800°F$ ($1538°C$). The MgO lining will react with uranium above this temperature increasing the oxygen content, the amount of slag, and also evolving magnesium vapor. Molten uranium above $2800°F$ will react strongly with a graphite crucible and cause erosion of the crucible. This results in an increased carbon content of the melt.

Uranium alloys readily with many other elements; titanium, molybdenum, columbium, and zirconium all go into solution readily and furnace losses are small. It is standard procedure to heat to $2750°F$ ($1510°C$) to insure solution and homogeneity of the melt, and then cool to the tapping temperature, which is $100-200°F$ ($37.8-93°C$) above the liquidus of the alloy.

The vacuum melting operation is unique in that the daughter products

TABLE VII

SOME MECHANICAL PROPERTIES OF U-Mo BASE ALLOYS

Nominal Composition and Heat Treatment	Tensile Properties at Room Temperature				V-Notch Charpy Impact at -40°F (ft-lb)
	Y.S. .1% ksi	T.S. ksi	Elon. (%)	R.A. (%)	
U-2%Mo					
As Extruded	81.5	166	10	14.0	4.7
Solutionized and Quenched	89	184	-	-	7.3
U-8%Mo					
As Cast	125	128	5	12.6	3.0
As Extruded	143	146	14	53.0	5.9
U-8%Mo-0.5%Ti					
As Extruded	149	165	11	32.8	3.2
U-8%Mo-1%Ti					
As Extruded	154	156	12.9	38.0	2.8
U-4%Mo-2%Cb-2%Zr-2%Ti					
As Extruded	140	171.5	7.3	25.5	4.2

TABLE VIII

SOME MECHANICAL PROPERTIES OF U-Cb BASE ALLOYS

Nominal Composition and Heat Treatment	Tensile Properties at Room Temperature				V-Notch Charpy Impact at -40°F (ft-ib)
	Y.S. .1% ksi	T.S. ksi	Elon. (%)	R.A. (%)	
U-4%Cb					
As Extruded	152.5	175	3	5	4.7
Solutionized and Quenched	38.5	169	20	19.1	12.1
U-4%Cb-0.5%Ti					
As Extruded	157.5	224	-	-	4.4
Solutionized and Quenched	30	162.6	28.6	32.6	15.5
U-8%Cb					
As Extruded	78.9	195	7.9	-	7.3
Solutionized and Quenched	37	117.4	28.6	58.1	17.1
U-8%Cb-0.5%Ti					
As Extruded	78	162	9	47	8.6
Solutionized and Quenched	96	135	12.9	46.5	6.4

TABLE IX

SOME MECHANICAL PROPERTIES OF U-Zr BASE ALLOYS

Nominal Composition and Heat Treatment	Tensile Properties at Room Temperature				V-Notch Charpy Impact at -40°F (ft-lb)
	Y.S. .1% ksi	T.S. ksi	Elon. (%)	R.A. (%)	
U-4%Zr-1.75%Cb					
As Extruded	163	275	9	-	7.3
Solutionized and Quenched	114.5	-	-	-	7.3
U-6%Zr-1.75%Cb					
As Extruded	148.5	263	10	-	5.2
Solutionized and Quenched	121	218	-	-	6.2
U-4%Zr-1.75%Cb-1%Ti					
As Extruded	190	244	-	-	2.1
Solutionized and Quenched	72.5	-	-	-	12.4
U-6%Zr-1.75%Cb-1%Ti					
Solutionized and Quenched	99	196	7.1	8.2	7.5

TABLE X

SOME MECHANICAL PROPERTIES OF ALLOY U-2%Mo-2%Cb-2%Zr-0.5%Ti

Nominal Composition and Heat Treatment	Tensile Properties at Room Temperature				V-Notch Charpy Impact at -40°F (ft-lb)	Hardness Rc
	Y.S. 0.1% ksi	T.S. ksi	Elon. (%)	R.A. (%)		
As Cast	180	200	1	2.6	2.7	-
As Extruded	169.5	234	8	16.2	6.8	-
As Extruded	188	245	2.1	7.6	4	-
Solutionized and Quenched	27.2	134.4	24	24.7	18.4	10
Solutionized, Quenched and Aged	148.5	172.8	7	5.2	5.2	40
Solutionized, Quenched and Aged	176	191	5	13.4	3.2	43
As Extruded	222.8	301	2.5	-	3.2	50

FIGURE I
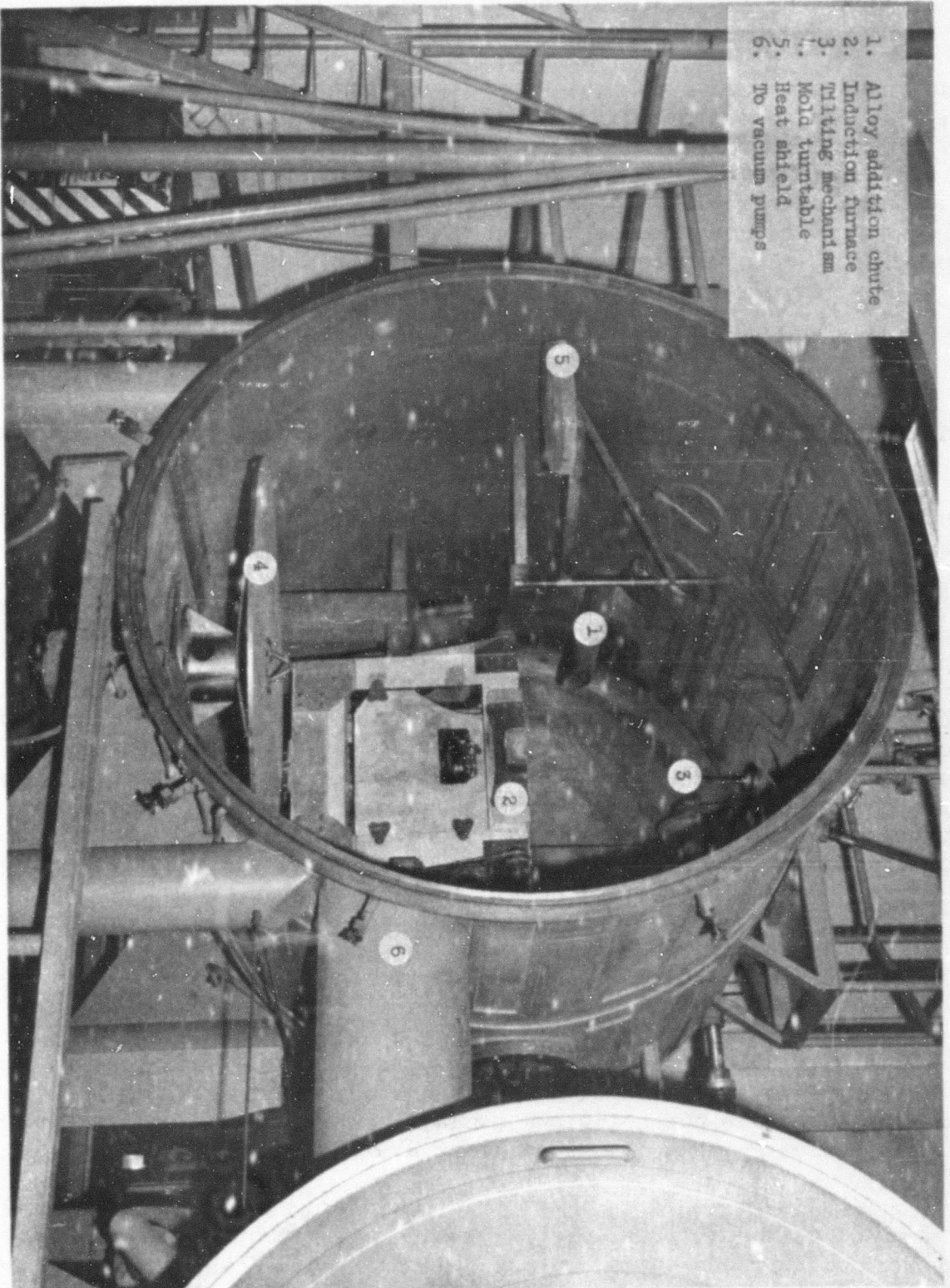
1. Alloy addition chute
2. Induction furnace
3. Tilting mechanism
4. Mold turntable
5. Heat shield
6. To vacuum pumps

VACUUM INDUCTION MELTING FURNACE — HIGH CAPACITY

(1st and 2nd decay step) of uranium are brought to the surface of the melt and are found in the slag, the surface of the melt, and the lining of the furnace. This radioactive material must be removed. After pouring, the top surface of the ingot is cropped and the sides are machined under local exhaust ventilation (See Figure 2). Observance of health physics rules is important in this operation.

Patching of the furnace lining after each melt results in another health physics problem involving external radiation and air-borne particulate matter. Table XI shows the average beta radiation measured from typical melts of uranium. The melters must patch the lining with a refractory material to prevent the uranium from reaching the induction coil. Experience has shown that if this should happen especially under vacuum conditions, an explosion may result. Shielding the personnel who perform this job is difficult because of the freedom of movement required for the operation. Gloves and lead aprons are unsatisfactory. One solution is to use a movable aluminum shield which is placed inside the furnace (See Figure 3). Aluminum was chosen since higher atomic number elements produce Bremsstrahlung radiation when exposed to beta radiation. The beta radiation associated with the daughter products has an effective range of 1100 centimeters (433 inches). This is more than enough to penetrate the epidermes layer of skin and may potentially cause beta burns. However, the aluminum shield is only open in that quadrant in which the worker is either cleaning or patching the lining. Even with the shield, the worker must be limited as to the amount of time spent in the furnace. Respirators are required during the patching operation and in some instances air-supplied units are provided.

Radioactive daughter product waste material is stored in labeled and segregated steel barrels as no further bulk reduction or incineration is required for waste disposal.

All vacuum cleaners used in the melting area should be provided with absolute filters with efficiency better than 99%.

Casting

Molds are of two basic types: permanent molds of graphite, and expendable molds of zircon (zirconium orthosilicate; $ZrSiO_4$). The graphite molds can be used bare in some cases, but they do not last because the uranium does react and stick to them. It is common practice to wash the molds with a duplex coating of zircon and mullite $(2SiO_2 \cdot 3Al_2O_3)$. This wash will prevent any contact between the molten uranium and the graphite. It also facilitates removal of the casting from the mold and increases the life of the mold. Expendable molds made of sintered zircon are excellent and very sound castings can be obtained in them.

When graphite crucibles are used for casting uranium, they must be machined after each heat. Considering that the crucible is now contaminated with radioactive daughter products, the ventilation problem during machining operation requires careful consideration. Air-borne particulate matter may

TABLE XI

AVERAGE BETA RADIATION MEASURED FROM TYPICAL URANIUM MELTS

Wgt. of Uranium Melt	Avg. Range Measured Beta Radiation Dosage	Avg. Measured Beta Radiation Dosage
200 lbs.	0.5-1.5 rem	1 rem
500 lbs.	1-2.5 rem	1.75 rem
3000 lbs.	5-15 rem	10 rem

TABLE XII

CHEMICAL AND MECHANICAL PROPERTIES OF ROLLED U-8%Mo BARSTOCK

Molybdenum (%)	7.9	7.98	8.05
Carbon (ppm)	108	50	135
Iron (ppm)	105	72	77
Oxygen (ppm)	23	34	11
Hydrogen (ppm)	0.8	0.5	Not Detectable
Nitrogen (ppm)	78	51	45
Density gm/cc	17.6	17.5	17.5
Yield at 0.1% offset (Avg. of 2 specimens)ksi	130.5	127	131.9
Elongation (%) (Avg. of 2 specimens)	14	13	15
Reduction of Area (%) (Avg. of 2 specimens)	50	51.9	53.2
Charpy (ft-lbs) (Avg. of 2 specimens)	6.3	5.5	6.8
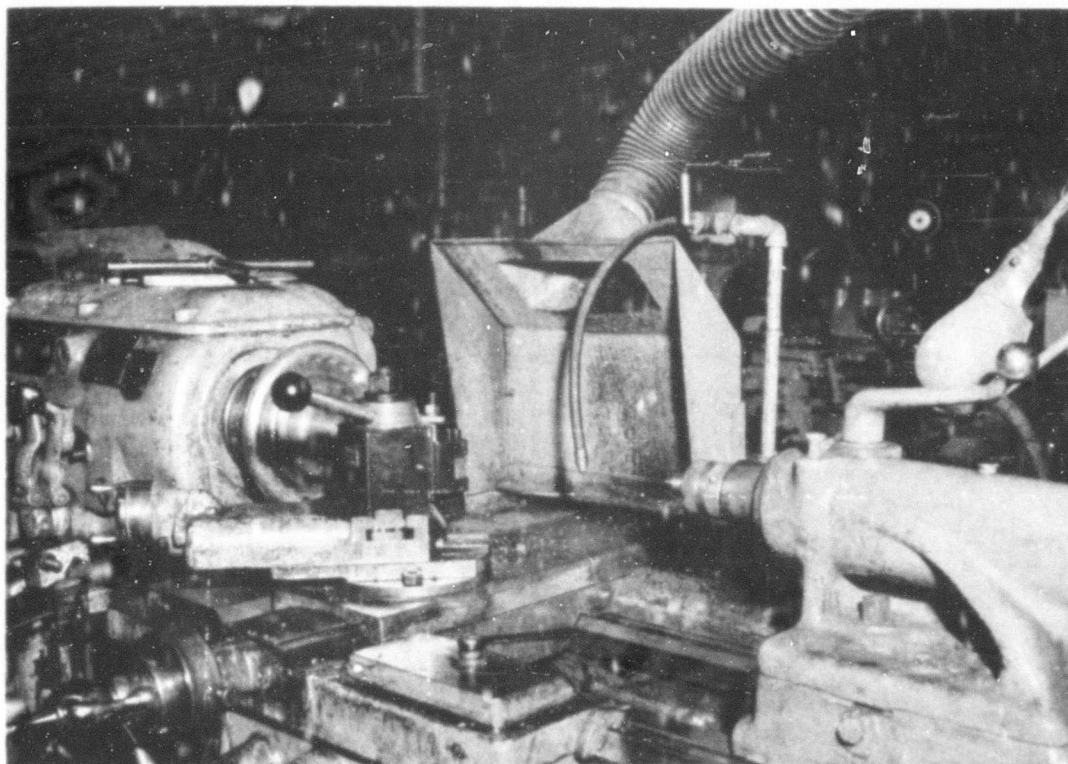
TYPICAL EXHAUST VENTILATION SYSTEM FOR URANIUM MACHINING OPERATIONS
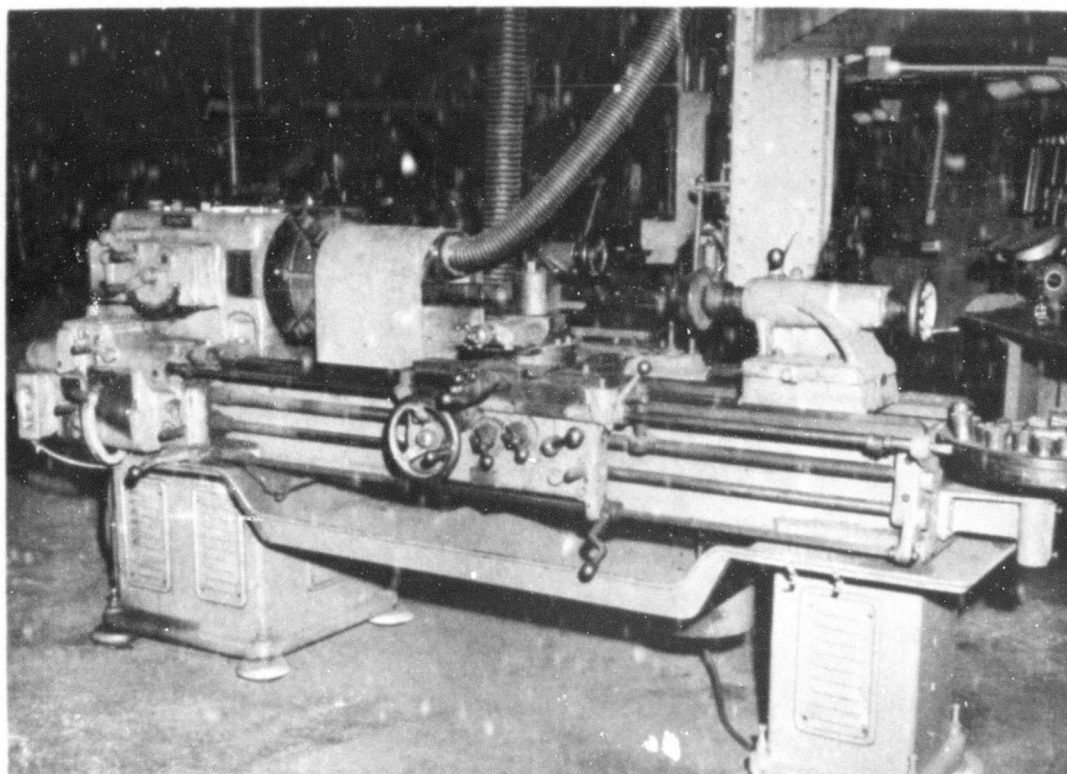
SHEET METAL-PLEXIGLASS HOOD USED FOR MACHINING URANIUM

24   FIGURES 2a & 2b

ALUMINUM SHIELD

INDUCTION COILS

FURNACE LINING

FURNACE WALL

URANIUM SLAG RESIDUE
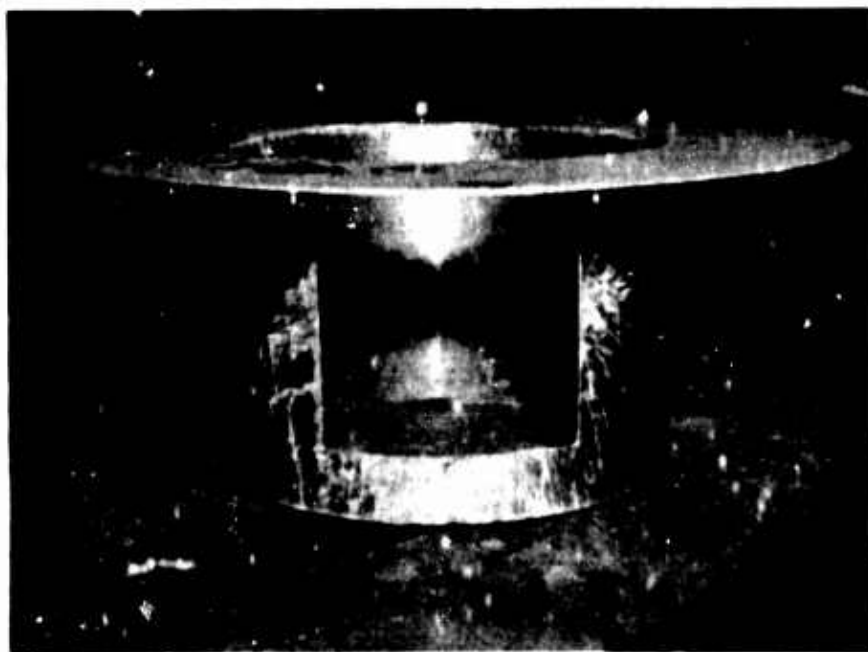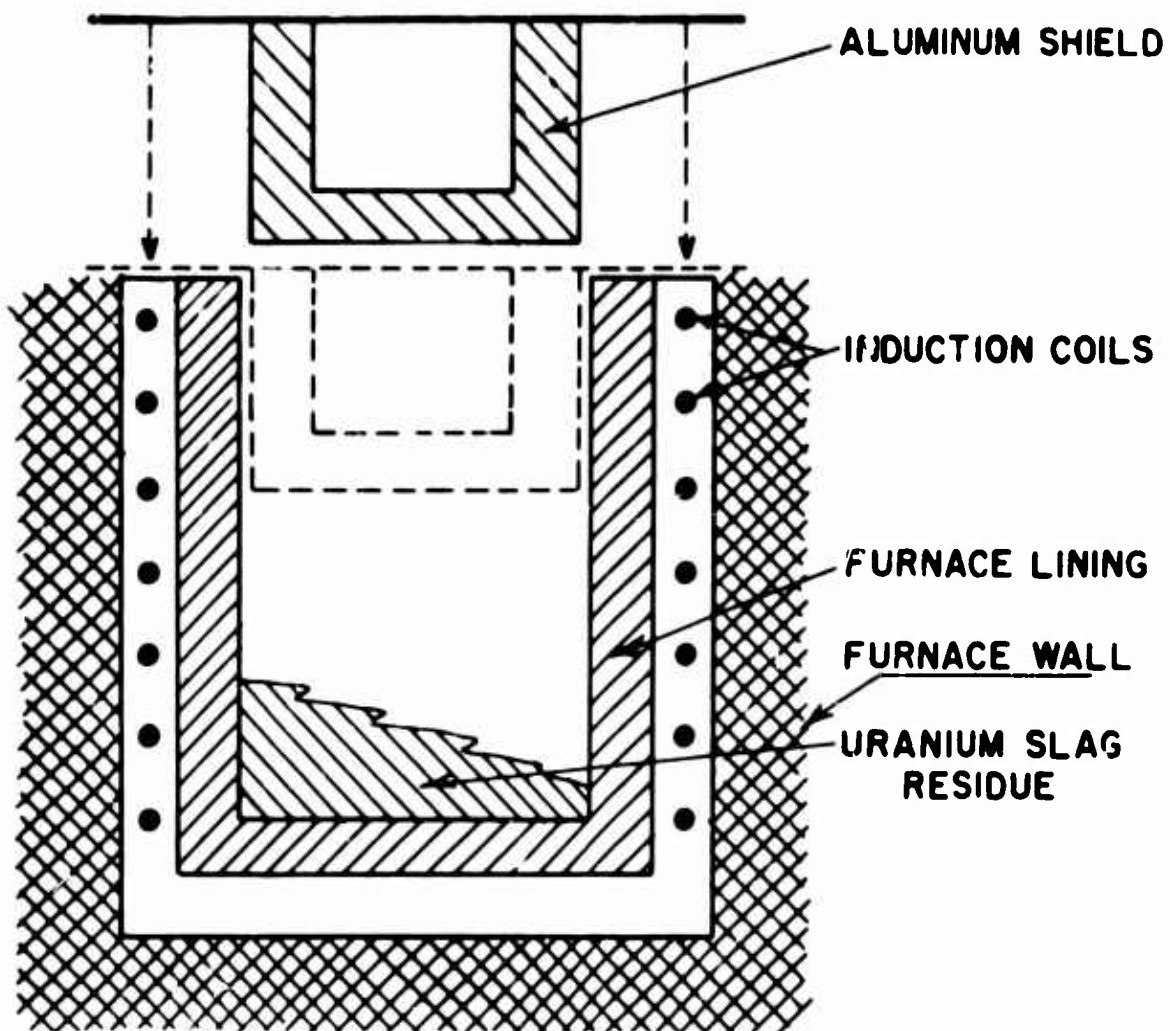
CROSS-SECTIONAL VIEW OF VACUUM INDUCTION MELTING FURNACE SHOWING USE OF ALUMINUM BETA RADIATION SHIELD FOR PATCHING TOP PORTION OF FURNACE LINING

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FIGURE 3

be far above the maximum acceptable concentration. A completely enclosed ventilating system should be used. A hood enclosure of a combination of sheet metal and lucite plastic is satisfactory.

Air samples taken in the vacuum casting area are evaluated for both total alpha activity and total daughter-product (Th^{234} and Pa^{234}) activity. Two-stage air samplers which differentiate between the respirable and non-respirable particles should be used. In addition, a modified cascade impactor designed by the New York Operation Office of the U. S. Atomic Energy Commission Health and Safety Laboratory is preferred. This impactor separates the particles into five particle size ranges. The particles are fixed into a pregreased glass slide and evaluated by nuclear counting techniques. The results are expressed in total activity per particle size range. These techniques have shown that a fair proportior of the respirable particulate matter is from the daughter products.

Heat Treatment of Castings

The heat treatment of castings naturally depend on the alloying elements used. As a rule, "as-cast" castings are brittle. However, small chill cast U-8% Mo alloys can be ductile while small castings of the same alloy in refractory molds are glass brittle. These alloys form a brittle delta phase if they are slowly cooled; in the 8% Mo alloy this phase can be dissolved by solution treating the castings at 1500 to $1600^{o}F$ (816 to $871^{o}C$) and oil quenching. After solution treatment, the castings have adequate ductility for most applications.

Section 3 - Hot Working

Rolling

There has been extensive experience and capability developed in the rolling of U-8% Mo alloy both in round and square bar form. This alloy has been rolled with a cladding on a square uranium bar utilizing flat rolls. Two temperatures were utilized, $1300^{o}F$ ($704^{o}C$) and $1450^{o}F$ ($788^{o})$. The square sections were reduced from 1.50 in. square down to 0.50 in. square.

It has been found possible to roll cast uranium alloy billets 2.50 in. diameter x 18 in. long down to 0.925 in. diameter x 150 in. long. These bars were water quenched after rolling to retain the gamma phase. Straightness was excellent. The rolling mill pass schedules consisted of 9 passes on cut rolls on a one-high, 24 in. rolling mill. Eight of the passes were required for reduction and the 9th for sizing and straightening. Due to the relatively low speed of the rollers, the barstock chilled substantially during passes. Consequently, five to eight reheats were required. Billets were heated in neutral salts at $1800^{o}F$ ($982^{o}C$).

Material has also been processed rolled from 5.25 in. diameter to 1.25 in. diameter and a total of seventeen passes were required. The

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first phase of the pass schedule required nine passes to reduce the 5.25 in. diameter billet to 3 in. diameter at 1800°F in one heat. The 3 in. diameter billet was then allowed to cool and cut to 14 in. lengths. In the second phase this 3 in. diameter bar was rolled at 1700°F to 1.25 in. diameter in seven passes. This was also performed in one heat. Consequently, a total of 17 passes were required for this operation.

Table XII shows typical chemical and mechanical properties taken from production samples. The U-8% Mo alloy barstock was rolled from 2.50 in. diameter to 0.925 in. diameter.

Forging

Forging of uranium is not as difficult as would be expected from its chemical reactivity. Molten salt is used in preheating; it clings to the uranium and prevents it from reacting with steel tools. Preheating temperatures of 1650 to 1800°F (899 to °C) have been used with equivalent success. The parts heated to the upper end of the range usually are worked more and therefore show ductility equivalent to those forged in the lower part of the range.

The condition of the starting material has a great effect on forgeability and it has been found essential to start with sound castings. Large castings with microporosity will break up during forging. However, a sound, well soaked-out casting may be forged very well. It is desirable to work the surfaces of large billets to refine the structure prior to making large reductions. It is good practice to include dye penetrant inspection for porosity of all cast forging stock.

The U-8% Mo is more resistant to forging reductions than low alloy steel; for example, a 2,000 lb. hammer is limited to about 2.50 in. diameter of uranium while it will easily forge 5 in. diameter steel stock. The lower strength alloys of uranium forge much easier and a low alloy content approach the workability of brass.

The amount of work necessary to produce optimum ductility and strength depends on the section size. However, a reduction of 50% will produce as good mechanical properties as greater reductions, providing the cast stock is of good quality. It is desirable to keep the percent reduction to a minimum because the surface of the uranium normally contains a large number of seams. These seams propagate in repetitive working and require greater stock allowances. As a rule 0.0625 in. to 0.1875 in. excess stock is left on all surfaces to insure that all surface defects and contamination will machine off after forging.

Health physics precautions are not stringent in press forging because there is very little airborne contamination. However, molten salt does splatter about during hammering and airborne contamination is serious enough to require employees to wear respirators.

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Extruding

The hot extruding of uranium and uranium alloys exhibits no insurmountable difficulties if proper processing and billet preparation procedures are used.

Some extrusion work has been accomplished on a 500 ton extrusion press shown in Figure 4 and a 1000 ton forging press shown in Figure 5. Typical solid extrusions are shown in the upper part of Figure 6 (U-8% Mo-1" dia) and a typical tubular extrusion is shown in Figure 7 (U-8% Mo-0.50% Ti).

The 1000 ton press is capable of backward extruding uranium alloy cylinders up to 8 in. in diameter and the 500 ton press that is used for forward extruding can accommodate extrusion billets up to 3.50 in. in diameter.

The forward extrusions studied consisted mainly of reducing 3.44 in. diameter extrusion billets to approximately 1.50 in. and 1 in. diameter extruded bars, (See Figure 8) having extrusion ratios of 5.45:1 and 12.25:1. All of the extrusion billets were flame sprayed with copper and the resultant extrusions exhibited acceptable surface condition and dimensional variations.

Lubrication. A flame sprayed copper lubricant is used on the extrusion billet. Graphite backup slugs 3.25 in. diameter x 1.50 in. long are also used to insure good extrusions and aid in lubrication.

Safety Precautions. No special safety precautions are considered necessary with the exception of conducting proper "clean-up" after extrusion was completed. The heating of the billets is conducted in properly vented salt baths.

Extrusion Procedures. The alloys extruded, the billet sizes, die angles, and the extrusion temperatures used are shown in Table XIII.

Mechanical and Physical Properties.

(1) As-extruded mechanical properties obtained from backward extrusions processed on a 1000 ton forging press are shown in Table XIV. The results were obtained from test specimens machined from 6.50 in. OD x 0.625 in. wall x 12 in. long cylinders of U-8%Mo alloy (See Figure 7).

(2) Mechanical properties obtained from extruded bar stock (See Figure 8) processed on a 500 ton horizontal extrusion press are shown in Table XV.

FIGURE 4

1,000,000-LB CAPACITY EXTRUSION PRESS
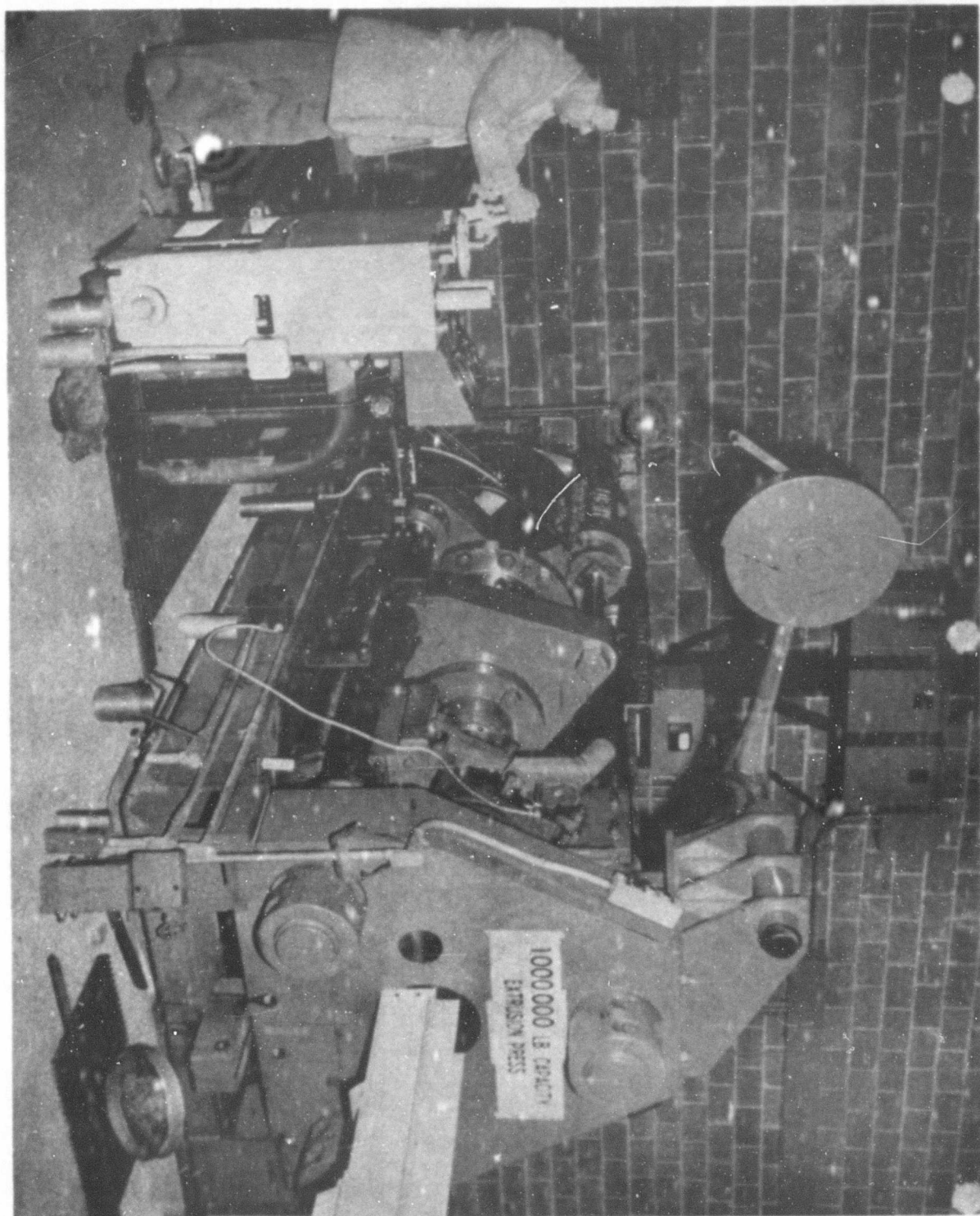
1000,000 LB CAPACITY
EXTRUSION PRESS

FIGURE 5
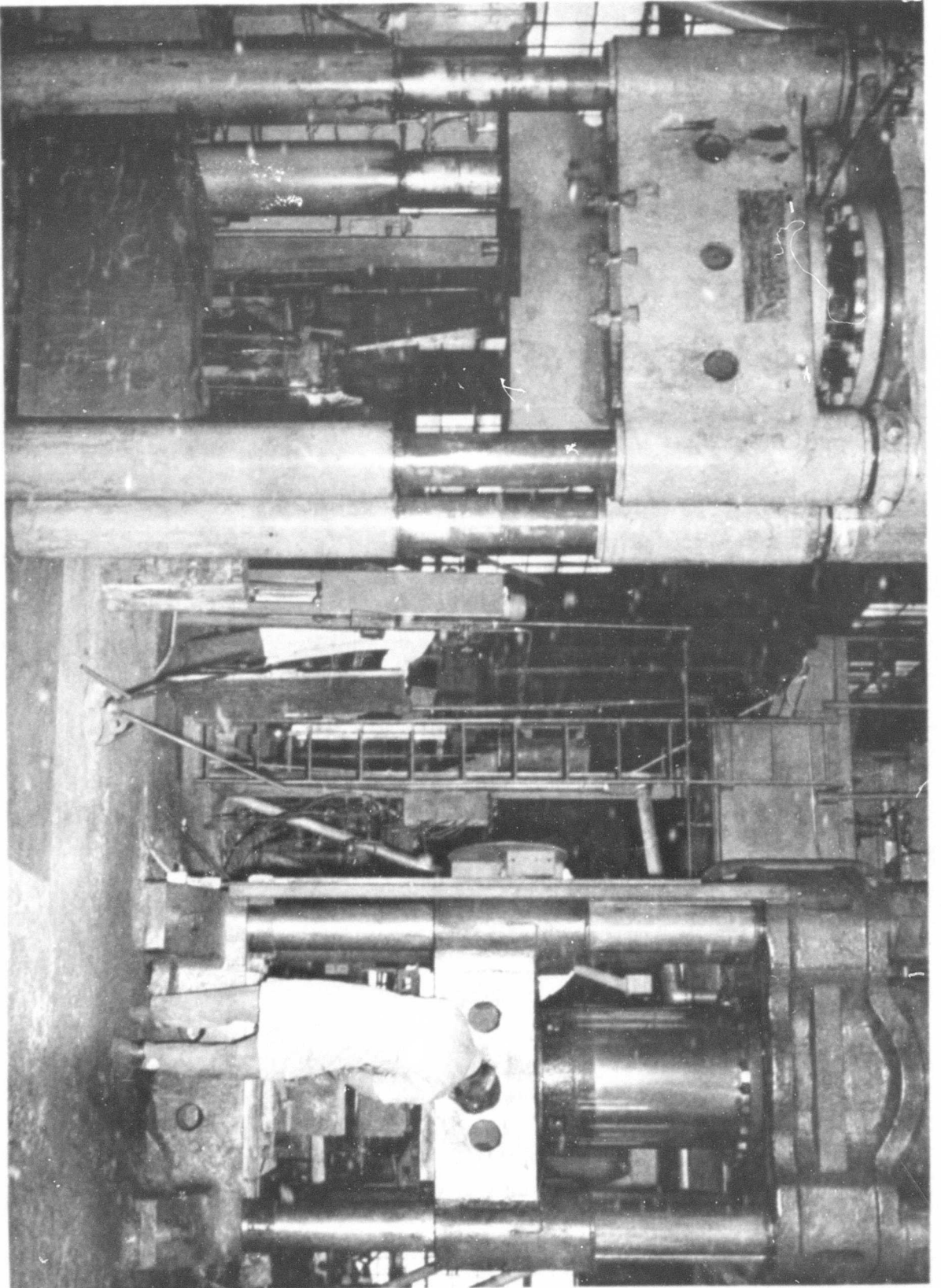
FORGING URANIUM ON 500 AND 1,000 TON FORGING PRESSES
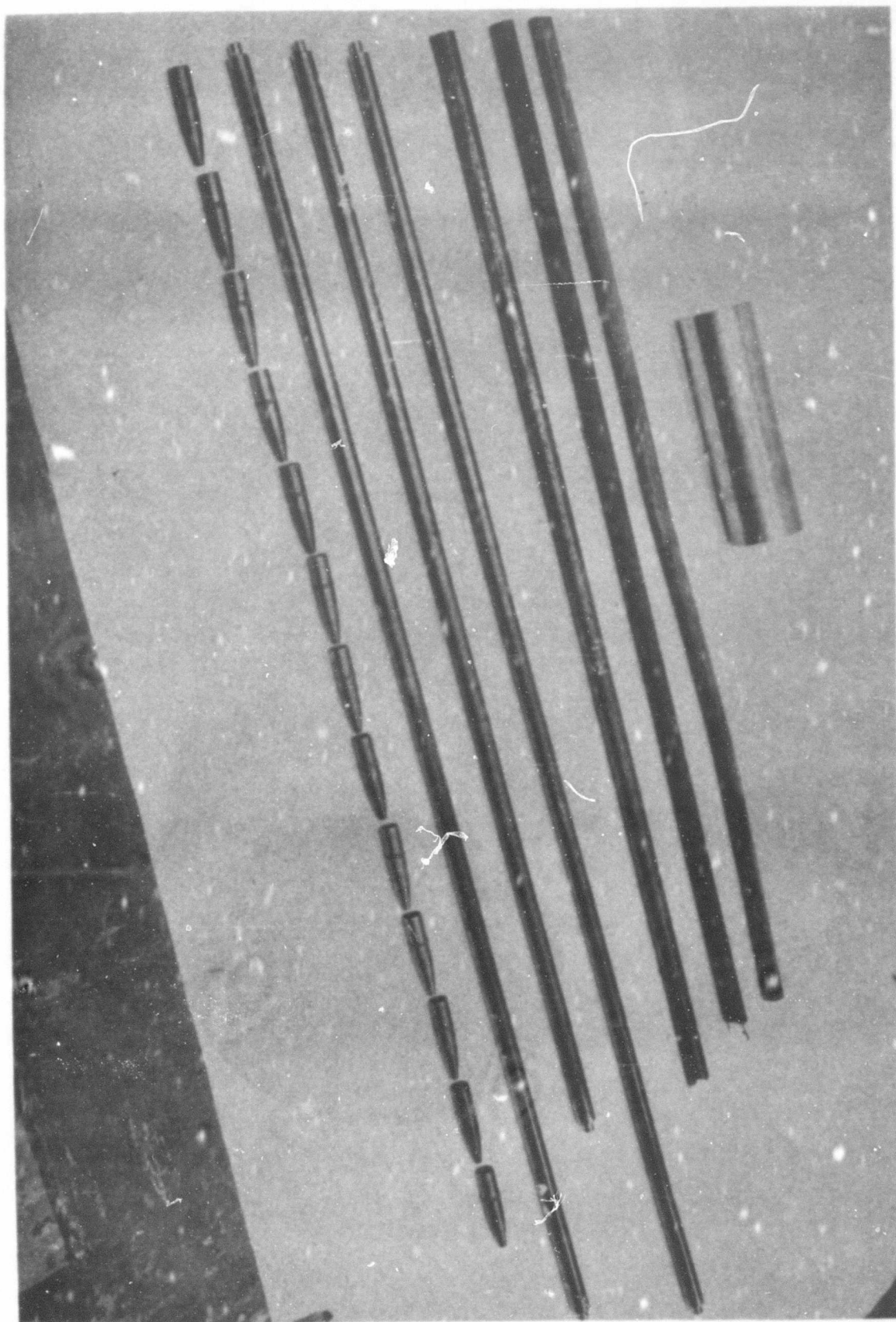
URANIUM ALLOY BAR STOCK, XM 101 BILLET, EXTRUDED BAR, SWAGED BAR, FINISHED PIECES

FIGURE 6
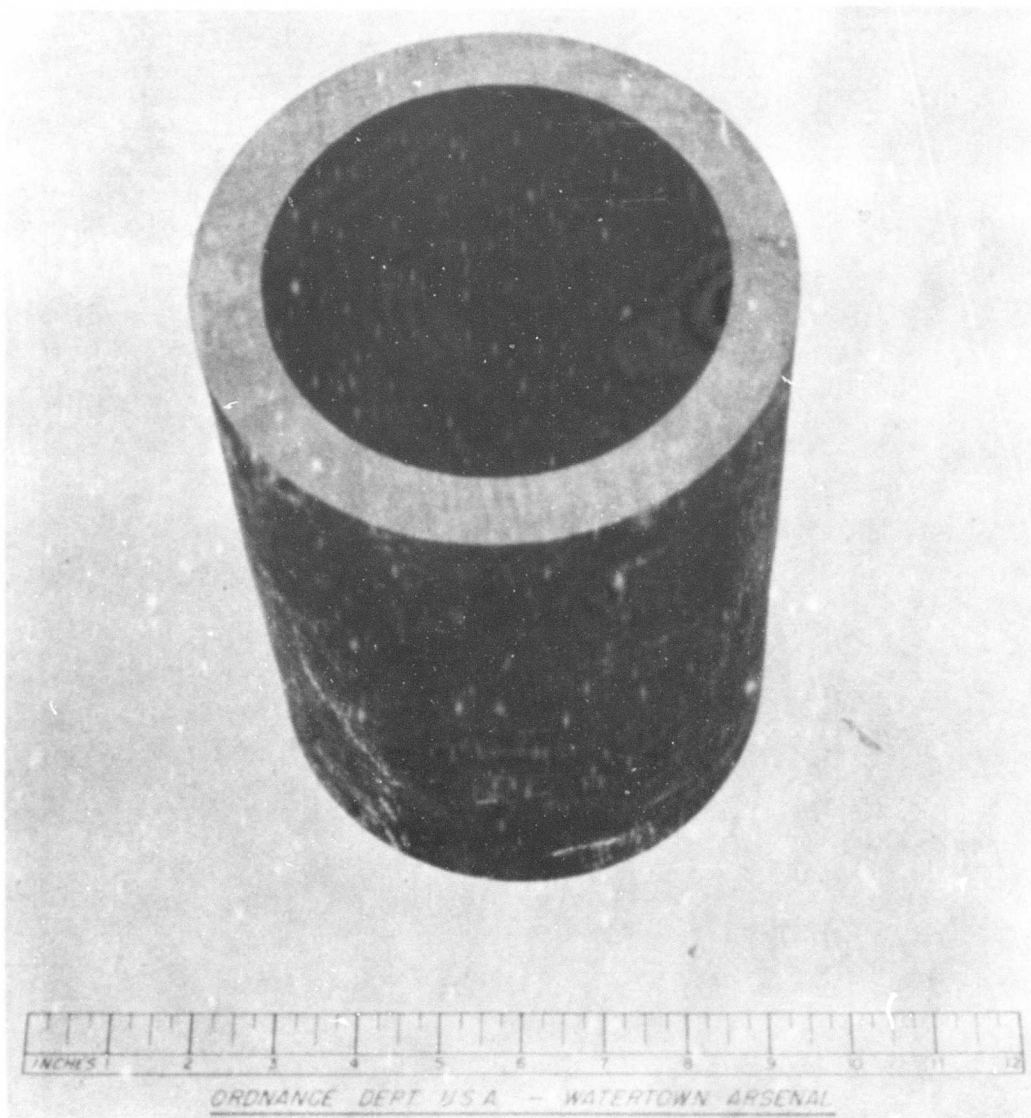
AS-EXTRUDED URANIUM CYLINDER

FIGURE 7

ORDNANCE DEPT. U.S.A. —- WATERTOWN ARSENAL
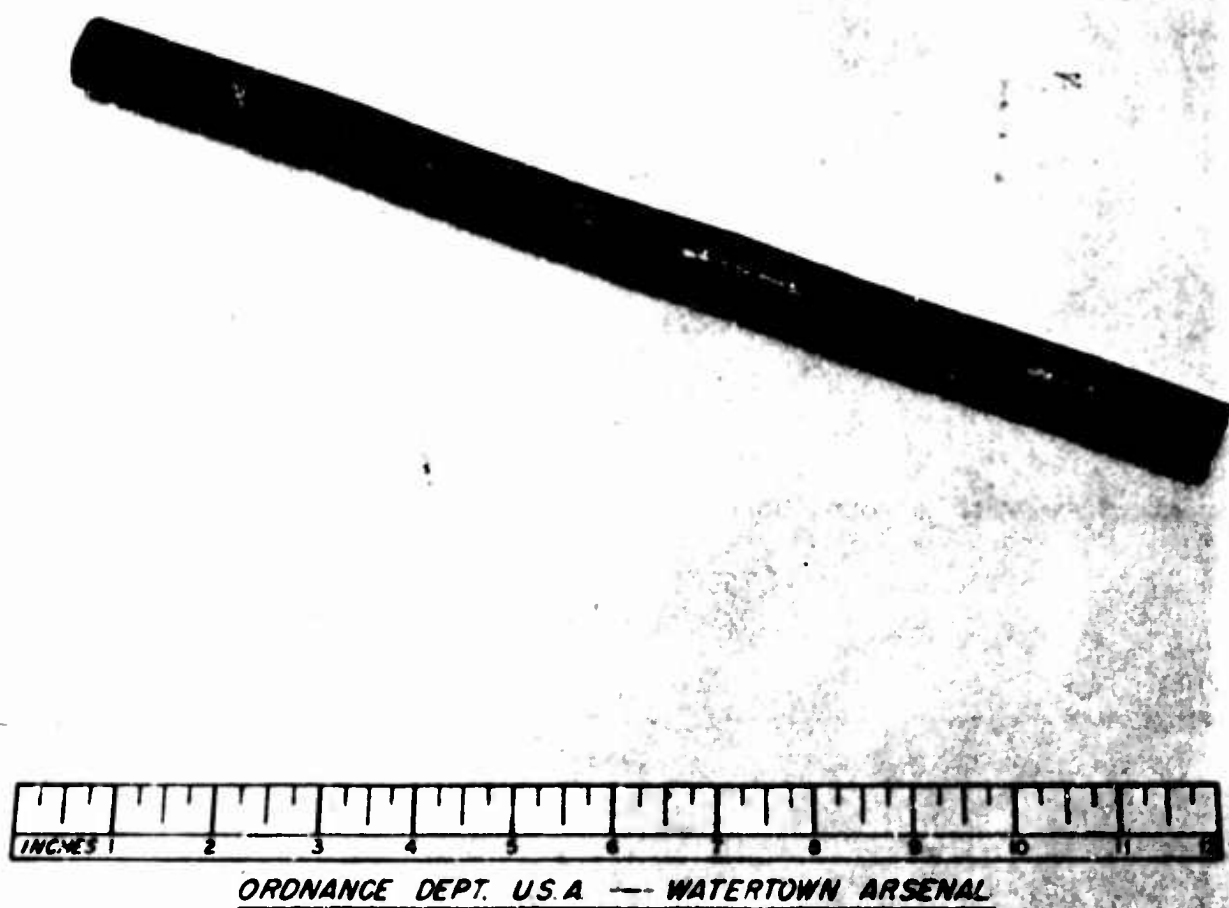
AS-EXTRUDED COPPER-COATED URANIUM ROD

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FIGURE 8

TABLE XIII

EXTRUSION DATA

Die Size and Angle	Alloy	Extrusion Temperature
1" - 20°	U-2%Mo-2%Cb-2%V-0.5%Ti	1650°F (899°C)
1" - 20°	U-2%Mo-2%Cb-2%Zr-0.5%Ti	"
1.5" - 25°	U-10.5%Mo	"
"	U-8%Mo-1.75%Ta-0.75%Ti	"
"	U-10%Mo-2%Ta	"
"	U-8%Mo-0.75%Ti	'
1" - 25°	U-8%Mo	"
1" - 45°	U-8%Mo	"
1.5" - 25°	U-2%Zr-2%Mo-2%Co-0.5%Ti	one at 1650°F & one at 1450°F (788°C)

All dies with a round bore.

Container Temperature - 750°F (399°C)

TABLE XIV

MECHANICAL PROPERTIES OF A URANIUM ALLOY
BACKWARD EXTRUDED ON A 1000 TON FORGING PRESS

0.2% Y. S. (ksi)	Elon. (%)	R. A. (%)	V-Notch Charpy Impact at -40°F (ft-lb)	Type of Test
130	7.5	14.7	3.2	Ten~ile
135.25	12.0	33.4	3.2	Tensile
134	7.0	11.0	3.2	Tensile
148.5	11.0	34.0	3.2	Tensile
132.3	-----	-----	---	Compression
133.6	-----	-----	---	Compression
132.1	-----	-----	---	Compression
129.6	-----	-----	---	Compression

TABLE XV

MECHANICAL PROPERTIES OF URANIUM ALLOYS EXTRUDED ON A 500 TON HORIZONTAL PRESS

	Y. S. 0.1% offset (ksi)	T. S. (ksi)	El.%	R.A.%	V-Notch Charpy Impact at -40°F (ft-lb)
U-8%Mo-.65%Ti	145	146	16	52	3
U-1-1/4%Ta-1/2%Ti	140	*	5	10	3
U-2%Mo-2%Cb-2%Zr-1/2%Ti	227	294*	0	0	3
U-2%Mo-2%Cb-2%V-1/2%Ti	150	*	0	0	2
U-10.5%Mo	152	153	14	43	4

*Broke outside gauge marks

TABLE XVI

AS-SWAGED PROPERTIES OF U-8%Mo BARSTOCK

Y. S. 0.1%offset (ksi)	Density (g/cc)	R. A. (%)	V-Notch Charpy Impact at -40°F (ft-lb)	Dia. (in.)
125.	17.4	50.1	7	0.844
127.5	17.5	52.0	6	"
124.5	17.5	52.5	6	"
125.6	17.5	49.5	6	"
129.	17.4	46.2	6	"
124.	17.5	46.4	6	"
125.	17.6	49.8	7.4	"

<center>Section 4 - Cold Working</center>

Swaging

The cold forming or swaging of uranium alloys appears to present very little difficulty as far as the actual deformation process is concerned. Occasionally, cracking is observed with the U-8%Mo system from improper processing procedures (such as repeated heating for annealing purposes to temperatures above $1800°F$ ($982°C$) followed by air cooling instead of water quenching). A moderate amount of cold swaging has been done using the equipment shown in Figure 9. The apparatus shown in an Ingersoll-Rand swaging machine capable of handling stock up to 3 in. in diameter. In addition, it is capable of forming shaped surfaces in the internal diameter of tubular configurations.

The majority of the uranium deformation work performed on this machine consisted of reducing 1 in. diameter solid round stock of the U-Mo-Ti system to 0.844 in. $\pm$ 0.006 in. diameter swaged bar. The resulting surface finish was approximately 32 root mean square (rms). The entire reduction was performed in one operation without any difficulties.

The alloys studied were: U-8%Mo, U-8.5%Mo, U-8%Mo-1%Ti and approximately 900 ft. were reduced.

Lubrication. No special lubrication or surface protection was incorporated in the swaging operation. However, a lubricant was normally used which consisted of lubricating die-and-cutting oils (8 parts SAE 2075 oil + 1 part proprietary cutting oil. This lubricant, which is used in most swaging operations, also acted as a cooling agent. Figure 6 shows the appearance of a typically swaged bar (0.844 in. dia U-8%Mo). And the projectiles shown at the bottom were machined from this bar.

Safety Precautions. After conducting surveys health physics personnel indicated that no special measures would be required for normal swaging operations.

Mechanical and Physical Properties. The as-swaged properties of U-8%Mo barstock are shown in Table XVI In general, the as-swaged properties vary only slightly from the properties prior to swaging for the particular alloys studied.

<center>Section 5 - Machining of Uranium</center>

General

Uranium has certain unique machining characteristics. Tool bits give longer life when machine speeds are reduced and feed increased. High-speed tools used initially were replaced by longer lasting carbide throw-away tools. At first however, the carbide tool tips fractured abruptly instead

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BACK PRESSURE
ATTACHMENT

SWAGING HEAD

PUSH BUTTON STATION

SLIDE CARRIAGE

SLIDE

GEAR BOX

SLIDE DRIVE

MANDREL DRIVE

COLD SWAGING MACHINE
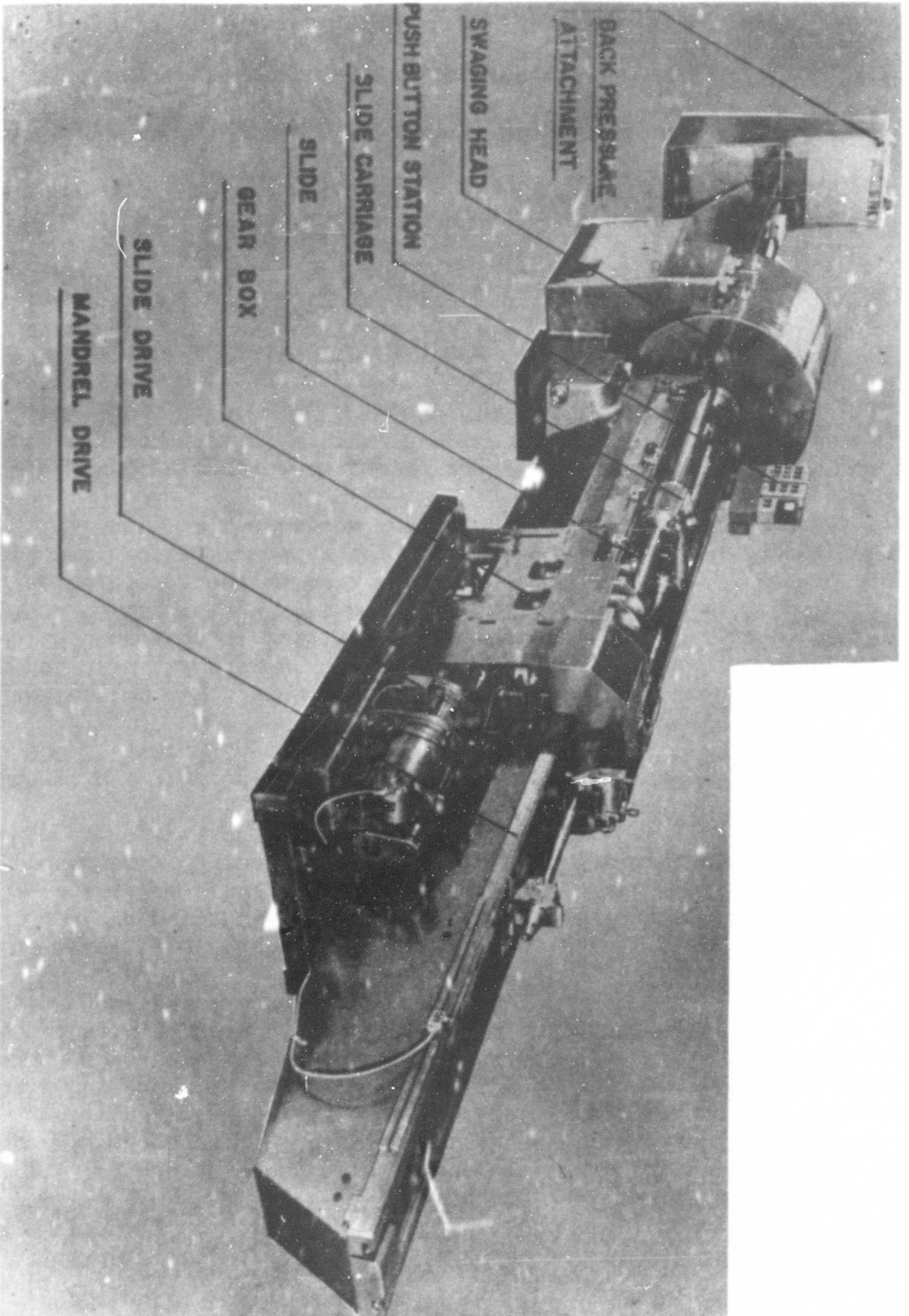
of wearing out gradually. This behavior was traced to lack of rigidity in the machine set-up and this problem was solved by tightening up the jibs and ways on the machine. Excess tool overhang and deflection was one more factor to be eliminated as this contributed to rapid tool breakdown. Satisfactory machining results were obtained by using carbide tools, by reducing overhang and by making all set-ups rigid.

Tooling

Machining of uranium with carbide tools requires rigid machines and a rigid set-up. "Throw-away" carbide inserts, one of the most economical types of cutters, are used because of their high productivity. Inserts can be rotated to expose three or four new cutting edges. Higher rotational speeds and heavier feeds can be used due to the heavier tool holders employed, and no time is lost picking up cuts. Grade 883* or equivalent carbide tips perform best on uranium and uranium alloys, both for roughing cuts and finishing operations. It is more economical to purchase new multi-point carbide inserts than it is to retip or regrind the cemented type.

Uranium is successfully cut by means of high-speed steel tools, but speeds and feed are slow, and tools are dulled quickly.

Uranium can be machined dry, but because of its pyrophoric characteristic it is advisable to use a coolant. A generous supply should flood both tool and work piece to prevent fires and to reduce contamination. Chips or turnings from machine tools should be kept at a minimum under the tool and work piece. As the material is being machined, the operator should clean away the chips to prevent fire. The pan under the lathe should be filled with coolant for the chips to fall into. This can be accomplished by the addition of an overflow pipe approximately 2 in. to 3 in. above the bottom of the pan. The coolant will not drain out until the level of the pipe is reached. The pan should be cleaned out frequently to prevent any accumulation of chips. Water soluble solutions are generally used as the coolant medium.

Milling

Milling is no problem if the speed is slow and the feed heavy. A guard should be provided to prevent the coolant and chips from spattering the area. Stubby cutters are used and the support arbor should be as close to the cutter as possible. All set-ups should be rigid with minimum overhang. Carbide cutters should be used whenever possible.

- -
*Carbology Department of General Electric Company

Drilling

Success in drilling uranium is obtained by adopting a "keep drilling" concept, using machine feeds. The drill is not allowed to "ride", and low speeds and heavy feeds should be maintained. The drill should be as short as possible. Carbide drills should be used whenever possible with a generous amount of coolant. Clearing the drill to wash out the chips will help to prevent work hardening of the material. For deep drilling the use of drills with coolant holes is best, because the coolant can be forced into the cutting area.

For very small holes an electro-spark erosion machine can be used with excellent results.

Tapping

Tapping screw holes can be very troublesome, particularly in tapping blind holes where chips can build up. The largest possible tap drill should be used. A rigid power set-up is better than hand tapping. A mixture of light machine oil and white lead, as well as molybdenum disulfide dispersed in a grease mixture have been used in the tapping operation. Commercial compounds such as UCON Lubricant and Rapid Tap have also been used. All of these lubricants appear to have a beneficial influence in the tapping operation.

Sawing

Uranium can be sawed using a coarse pitch blade with from two to six teeth per inch. Blades with high molybdenum content out-perform general purpose blades. Blade tension should be high, a simometer gage will help set proper blade tension. Rather slow speed and relatively heavy feeds are used; consistent with the cross-sectional area being cut and the power of the machine.

Accumulation of chips can cause a fire, therefore, the coolant should be fed with two nozzles to flood the work piece. The operator should rake away the chips at all times.

Abrasive Cut-Off Machine

An excellent means of cutting small pieces of uranium is to use a silicon carbide abrasive cut-off wheel. A conventional machine can be used, but a hood must be built to completely enclose the machine. Air samples should be taken during cutting to check the contamination. The exhaust vent should be built into the hood, and the door should have safety glass.

Shaping

A standard shaper can be used with a slight modification. A stainless steel.pan should be made to fit under the vise to collect the chips and

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coolant. The coolant hose is fastened to the tool post as the work is being cut, the coolant is always flooding the work piece at the cutting area.

Cleaning Machines

All machines used for uranium processing should be thoroughly cleaned at least once a month. Extensive use of a machine, or operations that would result in heavy concentrations of uranium sludge in the coolant, may necessitate cleaning at more frequent intervals.

The reasons for frequent cleaning of machines are many. It is good housekeeping practice and is also practical from the standpoints of safety and material accountability. As mentioned previously, an accumulation of fine uranium chips or particles could result in spontaneous combustion. This is particularly true if a machine is idle for a weekend, or longer, and the coolant evaporates leaving the uranium residue exposed to the air. For accountability purposes the coolant should be washed through a 200 mesh screen and the residue collected and stored in suitable containers. It is permissable to flush what passes through the 200 mesh screen down an ordinary drain. The sludge is then scooped out. The residue and the sludge are then weighed and recorded. It is good practice to schedule cleaning operations to coincide with monthly inventory checks.

Summary of Machining Techniques

(1) Use low   ; speeds

(2) Maintain high feed rates

(3) Always use a generous flow of coolants

(4) Use sharp tools and replace at the first sign of wear

(5) Never stop the feed while tool and work are in contact. A tool that is permitted to dwell causes work hardening.

(6) Uranium machines similarly to stainless steel

(7) Distortion of thin sections can be overcome by taking light finish cuts with a generous flooding of coolant and a newly sharpened and honed carbide tool.

(8) Machine must be rigid with minimum of back-lash

(9) Carbide tools must have honed edges for good tool life

(10) All machines must have exhaust vents and coolant systems

(11) Minimize overhang of cutting tools

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Grinding of Uranium and its Alloys

Silicon carbide grinding wheels are used with excellent results. It is important never to grind dry; fire and contamination hazards make the operation dangerous, and excessive residual stresses are introduced into the work. Grinding speed will vary somewhat with the particular alloy, and the choice of wheels.

Gaging

The abrasive and galling characteristics of uranium make the gaging of uranium items difficult. The use of an ordinary hand micrometer by a person not familiar with this material presents a problem. Tool-steel gage anvils do not stand up under repeated contact with uranium surfaces. The gages must have carbide contact points to assure accuracy of repeated measurements.

In the use of Acme Thread Gages it has been found that tool steel gages wear down much faster than the normal expectant life span of the gage. Steel thread gages have a tendency to stick and bind, sometimes entering freely, but may gall when the gage is backed out. Carbide seems to have a natural lubricating quality which eliminates this galling and picking up of metal on the thread flanks of the gage. In practice it has been found that a carbide thread gage with a pitch diameter several ten-thousands of an inch larger than its steel counterpart will enter more freely than the steel gage.

In the use of dial bore and dial snap gages it is more difficult to get correct readings because the galling of the uranium causes the indicators to jump and vibrate. Here again carbide anvils are a must, because steel anvils wear flat after little use.

In one particular set-up a 5/32 in. (0.15625 in.) diameter chrome-plated steel ball attached to a probe was used to measure the inside contour of a cylinder. The ball acquired a flat large enough to give false readings after approximately twenty readings had been taken. The steel ball was replaced with one of carbide and no further trouble was encountered.

Air gaging plugs that are continually being used in small diameter holes show a tendency to wear at the orifice causing inaccuracies in the readings.

In general, it must be emphasized that, to assure quality and inter-changeability of parts made of uranium, all gaging members or contact points should be carbide.

Fire Prevention Considerations

Fine particles such as those obtained in sawing operations, ignite spontaneously.

The use of water-base coolants, in conjunction with sharp tools will help to eliminate the danger of fire during the machining operations.

To minimize the threat of fire, the following suggestions have been found to be helpful:

(1) Maintain good housekeeping practices.

(2) Avoid unnecessary storage of chips and turnings. When stored they should be placed in metal containers and covered.

(3) Maintain electrical equipment to avoid sparks and electrical fires.

(4) Clean floors and equipment of all oil, grease and metallic dust daily.

(5) Remove rags and waste that are subject to spontaneous ignition.

(6) Collect chips and turnings regularly from machine pans at least once daily.

(7) Prevent sludge from drying before it is moved to an isolated and safe location.

(8) In case of fire, use those dry powders that have been developed for combustible-metal fires, such as "Metal X", powdered limestone, etc.

(9) Maintain dry powder containers within easy reach of the machinist.

(10) Do not use chlorinated hydrocarbon extinguishers or CO_2 extinguishers for uranium.

(11) Ventilate fumes from grinding or cutting machines to an exhaust system.

(12) Respirators should be available at all times and are to be used immediately in the case of fire.

Workers and visitors are required to wear protective foot covering to avoid carrying uranium contamination on the feet to areas outside the controlled area.

The purpose of the Health Physics control (See Chapter 5) is to prevent uranium from being spread around the area, where it would gradually build up a radiation background and interfere with experiments that require a low background.

Section 6 - Joining of Uranium

General

Uranium can be welded by fusion methods involving inert gas shielding. The inert gas shielded-arc method using a tungsten electrode and no filler metal is very satisfactory. Standard commercial equipment using a 400 amp rectifier power supply has been used for welding thin walled uranium cylinders. The inert gases* used in the shielded-arc welding process are dried by passing them through a commercial drier and further purified by passing through a tube of uranium chips held at 600°C (1112°F). The technique for welding uranium is very similar to that applicable to other nonferrous metals**. A uranium weld is comprised of a fusion zone and heat affected zones on either side of the fusion zone. During welding, some of the metal exists in the gamma phase, and upon cooling passes through the gamma and beta phases and ends up in the alpha phase. Upon examination, a residual gamma structure can be found. Adjacent to the gamma-transformed region the beta grain outline is retained in the structure. The fusion zone in welded uranium has a cast structure and contains large grains. Unlike the as-cast structures, the carbides are broken up into finely divided particles and are uniformly distributed throughout the fused area. From data supplied by the Los Alamos Scientific Laboratory it can be concluded that the tensile and yield strength of welded joints exceed the strength of the cast metal and the ductility was lower than that of the cast metals.

Integrity of Welds

Conventional radiographic techniques are generally used for the examination of welds. Where small defects are suspected a helium leak test has been used in some instances to supplement radiography.

Brazing

Dip brazing is used in fabrication of fuel elements for reactors. A metal-to-metal bond is formed on dipping uranium and aluminum into a molten aluminum-silicon alloy of eutectic composition. The metal reacts with molten Al-Si to form a thin adherent layer of U-Al-Si.

- -

*Inert gas recommended: 90% helium 10% Argon (% by vol)

**Special safety precautions are required during all welding operations, i.e. welding is done in a dry-box with proper exhaust through filters to insure a healthy environment for the personnel performing the welding operation.

Section 7 - Cleaning and Surface Treatment of Uranium

General

Because of its intrinsically poor corrosion and oxidation resistance, uranium generally requires special surface treatment or protection. Corrosion of uranium fuel elements in nuclear reactor coolants led to extensive research, by the Atomic Energy Commission, on protective coatings. In non-nuclear applications of uranium, special cleaning and surface treatments are also frequently required. Examples are: removal of heat treat scale from melting stock or from castings; prevention of oxidation prior to hot forming operations; lubrication during hot or cold forming; and preparation of surfaces for adhesive bonding.

Metal Coatings

Extensive studies on the cladding of uranium with a more resistant metal have been carried out under the Atomic Energy Commission program. Uranium fuel elements are generally protected simply by jacketing them in pure aluminum cans. Other claddings which have been employed in water cooled systems include Al-0.5% Ni alloy, zirconium, and stainless steel, depending upon the temperature of operation. A good diffusion bond between the cladding and the uranium fuel element is usually sought since a gap as small as 0.001 in. beneath the cladding is known to interfere seriously with heat transfer.

Considerable effort has been expended on all of the conventional metal coating methods with varying degrees of success, including electro-deposited coatings (from both aqueous and non-aqueous baths), chemical displacement coatings, hot-dipped coatings, evaporated coatings, etc. Uranium can be electroplated with a number of metals, utilizing conventional plating baths, but cleaning the surface prior to plating offers some difficulty. Where mechanical adhesion is acceptable or when a coating serves as an aid during forming of uranium metal, electrodeposits from aqueous baths are useful. However, for continuous, adherently-bonded deposits, non-aqueous organic type electroplating solutions are essential. However, such types of plating baths are not yet in common use.

In general, metal coatings are not recommended for protection of uranium and uranium alloys against corrosion during long term storage. The best protection is simply, freely circulating air, under which condition corrosion products tend to adhere to the metal. Considerable spalling occurs, however, under oxygen-depleted conditions, such as when barrier coatings are employed.

Scale Removal

There are several reasons why it is necessary to remove scale from uranium: as a prelude to electroplating; as a cleaning treatment for melting stock; and as a final treatment of castings.

Scale removal can be accomplished by mechanical abrasive blast clearing; by chemical treatments; by electrochemical treatments; or by a combination of any of these. These treatments may be preceded by vapor degreasing or cleaning in mild alkaline solutions to remove organic contaminants.

Ordinary dry blasting of uranium parts for removal of scale has been accomplished. Liquid abrasive blasting is also useful.

The following chemical solutions are recommended for removal of oxide and scale from uranium:

(1) Conc. Nitric Acid (HNO_3) 1 part by volume
     Water   1 part by volume
                    Room Temperature

(2) Orthophosphoric Acid (H_3PO_4) (85%)   5 parts by volume
     Conc. Nitric Acid (HNO_3) 1 part by volume
                    Temperature: $120^O F$

In using the orthophosphoric-nitric acid mixture it is sometimes desirable to interrupt the treatment of uranium alloy parts, rinse with water, dry, examine, and then re-pickle if necessary.

Anodic electrolytic treatments in the following solutions are also recommended for scale removal:

(1) Orthophosphoric Acid (H_3PO_4) (85%)   1 part by volume
     Water   1 part by volume
          Room Temperature
          Current density 0.6 - 1.2 amperes/square inch
          Cathode, stainless steel

(2) Chromic Acid (CrO_3) 1 part by weight
     Water   1 part by weight
          Room temperature
          Current density 0.6 amperes/square inch
          Cathode, stainless steel

(3) Conc. Sulfuric Acid (H_2SO_4) 75 parts by volume
     Water   25 parts by volume
     Chromic Acid (CrO_3) 10-15 grams per liter
          Temperature $120^O F$
          Current density 0.5 - 1.5 amperes/square inch
          (Best results are obtained at these operating conditions,
          although temperature and current density are not critical.
          The CrO_3 should first be dissolved in the water, before
          the sulfuric acid is added).

The last listed electrolytic treatment is frequently used following a chemical treatment in 1:1 nitric acid and water. The sulfuric-chromic

electrolytic treatment delays the appearance of visible oxidation of uranium; and a clean-looking surface can be maintained for several days and sometimes longer under normal atmospheric conditions. This treatment is useful for conditioning uranium prior to fabrication processes such as welding, rolling and drawing, where clean, smooth surfaces are important.

Oxidation Prevention During Hot Forming

Uranium requires protection from the atmosphere during heating. A coating of flame-sprayed copper provides satisfactory protection against oxidation and also functions as a lubricant during forging, rolling and extrusion of uranium alloys.

In preparing uranium alloys for flame sprayed copper, it is recommended that surfaces be dry blasted with angular steel grit (e.g. Pangborn #25) at 80-90 psi. A thickness of 0.0625 in. of copper is applied, using a wire feed gun, and oxyacetylene flame heating.

Sprayed ceramic coatings as well as metallic coatings have been successfully used in the forging of uranium alloys.

Lubrication During Forming Operations

In cold forming operations on uranium such as drawing and pressing, lubrication is a critical factor and various proprietary lubricants have been used. Electroplated metallic coatings such as silver or copper have been employed to facilitate drawing of uranium wires. Molybdenum disulfide and colloidal graphite dispersions are used as lubricants in the pressing of uranium components.

Preparation for Adhesive Bonding

A special technique[7] has been developed for bonding uranium, which is normally difficult to bond because it oxidizes rapidly to form a mechanically weak oxide layer. Tensile adhesive bond strengths (of the order of 1000 to 2200 psi) of test specimens remained essentially the same after storage for one year.

The technique involves abrading the bonding surfaces (for example, with No. 400 grit emery paper) in a pool of the adhesive until all visible oxide is removed and a white metallic surface can be seen through the adhesive film.

To assure maximum bond strengths it is vital that adjacent sides as well as the mating surfaces of uranium parts be similarly abraded under adhesive, since the oxide layer can spread from the uncleaned sides, with deleterious effects on bond strength.

The bonding surfaces are dipped in fresh adhesive immediately after abrading in adhesive, then assembled under slight manual pressure and subsequently cured.

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The polyamide-epoxy and polyurethane adhesives have given the best results for bonding uranium. Following are typical adhesive compositions:

Polyamide-epoxy	Parts by Weight
Bisphenol A epoxy	70
Polyamide resin	30

Polyurethane	
Polyurethane resin	100
Allylglycidyl ether	30
4, 4' - Methylene bis (2-chloroaniline)	9

Section 8 - Laboratory Testing

General

Commonly employed chemical, physical, mechanical, metallurgical, and nondestructive testing techniques employed on metallic materials are generally applicable to uranium alloys. Samples for testing are accompanied by a uranium transfer form (See Figure 13 After completion of the tests, any remaining samples of scrap material is returned to the person submitting the test or transferred to e uranium scrap cage for disposal; again accompanied by a transfer form. Solid or non-water soluble liquid waste are accumulated in special, identified receptacles and turned over to a health physicist for disposal. Water soluble liquid waste is flushed down the sink drains with copious quantities of water in order to provide an effective dilution. Testing operations and temporary storage of uranium, while in the laboratory, is confined to limited areas to prevent the contamination of radiation sensitive scientific instruments and materials. Before uranium materials are introduced to a laboratory area, a survey is made to make sure that the radioactivity introduced will not adversely affect the conduct or performance of other tests.

Chemical Analysis

General. Samples are usually prepared in the form of small cubes and chips which are stored in screw top glass containers. Although no unique controls or procedures are necessary for the analysis of uranium, film badges are required to be worn during testing. Typical analytical methods employed are shown in Table XVII and XVIII.

Mechanical Testing

Standard ASTM testing procedures are employed for hardness, tensile and impact testing. Quasi-static tensile testing is generally conducted at a rate of 0.005 in./in./min. However, uranium is quite strain rate sensitive and some tests are being conducted at a much higher strain rate

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TABLE XVII

CHEMICAL ANALYSIS OF DEPLETED URANIUM

Element	Method
Oxygen and Hydrogen (together)	Determined simultaneously in a vacuum-fusion apparatus
Hydrogen (alone)	Hot extraction
Nitrogen	Kjeldahl procedure using a Parnous-Wagner semi-micro distillation apparatus
Carbon	Combustion in an induction furnace, followed by either a gravimetric or by a conductometric measurement
Iron	Photometrically using o-phenanthroline
Silicon	Gravimetrically by dehydration with sulfuric acid
Copper	Photometrically with cuprizone
Nickel	Photometrically with dimethyglyoxime

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TABLE XVIII

CHEMICAL ANALYSIS FOR ALLOYING ELEMENTS

Element	Method
Molybdenum	Photometrically as either the thiocyanate or peroxide complex. If determined as the peroxide complex, corrections are necessary for uranium and titanium. Vanadium and columbium interfere with the latter method.
Titanium	Photometrically as the peroxide complex. A small correction is necessary for molybdenum.
Columbium or Tantalum	Gravimetrically by hydrolysis with sulphurous acid, when not accompanied by each other or alloying amounts of vanadium and titanium.
Zirconium	Gravimetrically with p-chloromandelic acid.
Vanadium	Volumetrically by titration with permanganate
Cobalt	Photometrically as a chloride complex

NOTE: In complex alloys containing columbium, tantalum, zirconium, etc., separation of the alloying elements by ion-exchange is necessary before making determinations.

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(0.3 in./in./min.) which more closely reflects the conditions encountered in the service performance of dynamically stressed components for Army applications.

Metallography

Micro-examination.

(1) Metallographic preparation, mounting and polishing are generally simlar to procedures employed for steel. Specimens are mounted in plastic molds at room temperature because the structure of some uranium alloys are affected by low temperature heating cycles. Polishing is performed with a lubricant to prevent airborne dust and minimize surface flow of the metal. Specimens are ultrasonically cleaned between each polishing operation. Materials employed for specimen preparation are listed in Table XIX. In step No. 8 of Table XIX, a slurry is made by mixing Linde "B" polishing powder in a water solution containing 1 percent hydrofluoric acid. This acid is quite efficient in removing surface flow. Care must be exercised, however, in handling this mixture because even minute quantities of this acid solution under fingernails can lead to prolonged and painful healing with probable loss of fingernails. Step No. 9 is primarily used to remove tarnish left by acid in step No. 8. The final polishing step is electrolytic using formula No. 1 in Table XX. Two, three-second dips are usually sufficient to remove any worked metal remaining after step 9.

(2) Sometimes formulas No. 2 and No. 3 are satisfactory in revealing the microstructure of uranium alloys but it is a common practice to etch uranium specimens by means of vacuum cathodic etching. Etching takes place in an atmosphere of argon at 12 microns pressure, 400 volts, and 5 to 10 milliamps for 12 minutes. The structure is then visible under light field illumination.

Macro-examination

(1) Specimens for macroexamination are polished through the 400 grit silicon carbide papers, using kerosene as a lubricant, then degreased and immersed in concentrated hydrochloric acid until a black deposit covers the surface. The specimens are then washed in hot water, dipped in concentrated nitric acid for a few seconds to remove the black deposit and finally rinsed thoroughly. This procedure is repeated until desired structure and contrast is evident.

(2) Care must be exercised when macroetching uranium alloys containing 10 percent or more zirconium or columbium. These alloys may produce an explosive condition when removed from either concentrated, or 50 percent water solutions of nitric or hydrochloric acid. It has been recommended that an addition of 6 grams of ammonium fluoride to 32 ounces of etching solution will prevent this explosive action.

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TABLE XIX

POLISHING PROCEDURES FOR URANIUM AND URANIUM ALLOY SPECIMENS

Step	Polishing Base	Grit	Lubricant	Pressure	Speed RPM	Time Min.
1	Silicon Carbide Paper	240	Kerosene	Moderate	N/A	N/A
2	" "	320	"	"	"	"
3	" "	400	"	"	"	"
4	Emery Paper	000	"	"	"	"
5	" "	"	"	"	"	"
6	Rayon Acetate Covered Wheel Diamond Abrasive	9 Micron	"	"	250	5
7	Broadcloth Covered Wheel Diamond Abrasive	3 Micron	"	"	250	5
8	Camel Cloth Al₂O₃ Abrasive	0.1 Micron	1% HF in H₂O	Light	250	2
9	Camel Cloth Al₂O₃ Abrasive	0.1 Micron	Alcohol	"	1150	2

TABLE XX

ELECTROLYTIC POLISHING AND ETCHING SOLUTIONS FOR URANIUM

Formula 1

	Cathode	Cathode-Anode Distance	Voltage	Time	Polish Etch
Ortho-phosphoric acid 5 ml Ethylene Glycol 4 ml Ethyl Alcohol 4 ml	Stainless Steel	1/2"	50	2 Dips (3 Sec.)	Polish

Formula 2

Chromium trioxide 25 grams Water 25 ml Glacial Acetic Acid 100 ml	Stainless Steel	1/2"	20	4 Dips (3 Sec.)	Etch

Formula 3

Chromium trioxide 25 grams Water 25 ml Glacial Acetic Acid 500 ml	Stainless Steel	1/2"	20	1 Min.	Etch

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TABLE XIX

Nondestructive Testing

It is only in comparatively recent years that consideration has been given to the use of uranium as a structural material and little non-destructive testing experience has been accumulated.

Radiography of uranium imposes special problems because of its high density and the fact that backscatter and secondary radiation effects impose special shielding and filtering requirements. Special techniques for optimizing the radiographic inspection of uranium have been devised for thicknesses up to 2.75 in. and have been reported[8].

Though preliminary work has been accomplished on the use of other nondestructive methods for the inspection of uranium, such as ultrasonics, eddy currents, and liquid penetrants, definitive data are not presently available, nor limits defined.

CHAPTER IV

URANIUM MATERIALS CONTROL

Section 1 - General

General

The purpose of this section is to describe the controls currently employed which have been set up to comply with the regulations for the procurement, storage, and control of uranium.

Licensing

Arrangements have been made to transfer uranium from the United States Atomic Energy Commission to the Department of the Army for non-nuclear military applications by United States Atomic Energy license. For spotting round material, License SUB-459 has been assigned (See Figure 10). United States Atomic Energy Commission regulations covering the licensing of source material (which includes uranium) are covered in Code of Federal Regulations Title 10, Chapter 1, Part 40 "Licensing of Source Material" (hereafter referred to as 10 CFR Part 40). Licensees are subject to provisions of the Atomic Energy Act of 1954 including any ammendments. In compliance with existing provisions, it is necessary for licensees to abide by the regulations of 10 CFR Part 20, "Standards for Protection Against Radiation Hazards" as well as 10 CFR Part 40.

Guidance

Guidance on procedures to be employed in the control of source material (including uranium) is provided in AEC Manual Part 7400 (Materials Management). Several Army Regulations are also applicable to the regulation and control of radioactive materials which includes uranium. These are listed as follows:

    AR 735-4   - "Property Accountability - Expendable Property"

    AR 735-5   - "General Principles and Policies"

    AR 735-10 -. "Principles and Policies - Accounting for Lost, Damaged,
                   or Destroyed Property"

    AR 735-11 - "Accounting for Lost, Damaged, or Destroyed Property"

    AR 735-25 - "Property Procedures"

    AR 40-580 - "Control of Health Hazards Procurement Procedures"

    AR 755-380- "Disposal of Radioactive Material"

Form AEC—440
(5-61)

UNITED STATES
ATOMIC ENERGY COMMISSION

SOURCE MATERIAL LICENSE

Pursuant to the Atomic Energy Act of 1954, and Title 10, Code of Federal Regulations, Chapter 1, Part 40, "Licensing of Source Material," and in reliance on statements and representations heretofore made by the licensee, a license is hereby issued authorizing the licensee to receive, possess and import the source material designated below; to use such material for the purpose(s) and at the place(s) designated below; and to deliver or transfer such material to persons authorized to receive it in accordance with the regulations in said Part. This license shall be deemed to contain the conditions specified in Section 183 of the Atomic Energy Act of 1954 and is subject to all applicable rules, regulations, and orders of the Atomic Energy Commission, now or hereafter in effect, including Title 10, Code of Federal Regulations, Chapter 1, Part 20, "Standards for Protection Against Radiation," and to any conditions specified below.

Licensee	
1. Name Department of the Army	**3. License No.** SUB-459
2. Address Washington, D. C.	**4. Expiration Date** October 31, 1964
	5. Docket No. 40-6639

6. Source Material	**7. Maximum quantity of source material which licensee may possess at any one time under this license**
Uranium	No quantity limitations.

CONDITIONS

8. Authorized use (Unless otherwise specified, the authorized place of use is the licensee's address stated in Item 2 above.)

For fabrication of spotting rounds at Lake City Arsenal, Independence, Missouri, and Frankfort Arsenal, Philadelphia, Pennsylvania, and for the testing of spotting rounds in accordance with the procedures described in applications for license submitted by the Ordnance Corps dated May 1, June 2, and September 26, 1961. The licensee is further authorized to distribute spotting rounds to field units of the Army and to use such rounds for military purposes in accordance with the procedures described in the licensee's September 19, 1961, application. This license authorizes the export of spotting rounds containing uranium for military purposes.

For the U. S. ATOMIC ENERGY COMMISSION

Date of Issuance ___NOV 1 1961___

Darrell A. Nussbaumer

★ U.S. GOVERNMENT PRINTING OFFICE 1961—O-581691

Division of Licensing and Regulation

UNITED STATES ATOMIC ENERGY COMMISSION SOURCE MATERIAL
LICENSE NO. SUB-459

FIGURE 10

Definitions (10 CFR 40 and 10 CFR 20)

"Act" means the Atomic Energy Act of 1954 (68 Stat. 919), including any amendments thereto;

"Commission" means the United States Atomic Energy Commission or its duly authorized representatives;

"Government agency" means any executive department, commission, independent establishment, corporation, wholly or partly owned by the United States of America which is an instrumentality of the United States, or any board, bureau, division, service, office, officer, authority, administration, or other establishment in the executive branch of the Government;

"License", except where otherwise specified, means a license issued pursuant to the regulations;

"Person" means (1) any individual, corporation, partnership, firm, association, trust, estate, public or private institution, group, Government agency other than the Commission, any State or any political subdivision of, or any political entity within a State, any foreign government or nation or any political subdivision of any such government or nations, or other entity; and (2) any legal successor, representative, agent or agency of the foregoing;

"Byproduct material" means any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material;

"Calendar quarter" means any period determined according to either of the following subdivisions:

(1) January 1 to March 31, inclusive; April 1 to June 30, inclusive; July 1 to September 30, inclusive; October 1 to December 31, inclusive; or

(2) The first period in a calendar year of 13 complete, consecutive calendar weeks; the second period in a calendar year of 13 complete, consecutive calendar weeks; the third period in a calendar year of 13 complete, consecutive calendar weeks; the fourth period in a calendar year of 13 complete, consecutive calendar weeks. If at the end of a calendar year there are any days not falling within a complete calendar week of that year, such days shall be included within the last complete calendar week of that year. If at the beginning of any calendar year there are days not falling within a complete calendar week of that year, such days shall be included within the last complete calendar week of the previous year. No licensee shall change the method observed by him of determining calendar quarters for purposes of this part except at the beginning of a calendar year.

"Individual" means any human being;

"Licensed material" means source material, special nuclear material, or byproduct material received, possessed, used, or transferred under a general or specific license issued by the Commission pursuant to the regulations in this chapter;

"Occupational dose" includes exposure of an individual to radiation (1) in a restricted area; or (2) in the course of employment in which the individual's duties involve exposure to radiation; provided, that "occupational dose" shall not be deemed to include any exposure of an individual to radiation for the purpose of medical diagnosis or medical therapy of such individual;

"Radiation" means any or all of the following: alpha rays, beta rays, gamma rays, X-rays, neutrons, high-speed electrons, high-speed protons, and other atomic particles; but not sound or radio waves; or visible, infrared, or ultraviolet light;

"Radioactive material" includes any such material whether or not subject to licensing control by the Commission;

"Restricted area" means any area, access to which is controlled by the licensee. "Restricted area" shall not include any areas used as residential quarters, although a separate room or rooms in a residential building may be set apart as a restricted area;

"Unrestricted area" means any area entry into which is not controlled by the licensee, and any area used for residential quarters except as noted above;

Definitions of certain other words and phrases as used in this chapter are set forth in other sections of 10 CFR including:

(1) "Airborne radioactivity area" defined in par. 20.203;

(2) "Radiation area" and "high radiation area" defined in par. 20.202;

(3) "Personnel monitoring equipment" defined in par. 20.202;

(4) "Survey" defined in par. 20.201;

(5) Units of measurement of dose (rad, rem) defined in par. 20.4;

(6) Units of measurement of radioactivity defined in par. 20.5;

"Source material" means (1) uranium or thorium, or any combination thereof, in any physical or chemical form, or, (2) ores which contain, by weight, one-twentieth of one percent (0.05%) or more of (i) uranium, (ii) thorium or (iii) any combination thereof. Source material does not include special nuclear material.

"Special nuclear material" means (1) plutonium, uranium 233, uranium enriched in the isotope 233 or in the isotope 235, and any other material which the Commission, pursuant to the provisions of section 51 of the Act, determines to be special nuclear material; or (2) any material artificially enriched by any of the foregoing.

Section 2 - Materials Control

General

This section summarizes the essential elements of the governing regulations and documents listed. These are cited for purposes of this monograph only.

Procurement of Uranium

Uranium and its alloys are obtained in several ways which are listed as follows:

(1) Transfer from the AEC. The Army after receiving allocations approval from the AEC, orders material through the AEC Oak Ridge Operations Office. The Oak Ridge Operations Office authorizes one of the operating plants of its contractors to supply the material and/or process requirements. Documentation of the transfer of material from the AEC to the Army installation is accomplished on AEC Form 101 (See Figure 11).

(2) Commercial Purchase. When the desired type of material is available from commercial producers it can be ordered directly as any other material.

(3) Transfer. Licensed uranium material may be obtained from another Army installation by transfer using the same procedures employed for other materials. Additional control requirements are noted subsequently. Transfer of material from Army installation to contractors under separate license is done using AEC Form 388(1-60) (See Figure 12).

Storage

In the control of uranium during storage it is important to comply with Regulations 10 CFR 20 and 10 CFR 40. It has been found advantageous to establish a locked uranium storage area at a location convenient to the receiving and shipping facilities of the installation.

The pyrophoric behavior of uranium when finely divided is of primary importance in selecting the storage area for this type of material. Chips and other pyrophoric material resulting from uranium processing operations are removed promptly from work areas and sent to designated storage sites, such as a uranium scrap cage, for storage under oil.

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UNITED STATES ATOMIC ENERGY COMMISSION SHIPPING FORM 101

FIGURE 11

UNITED STATES ATOMIC ENERGY COMMISSION

SS MATERIAL TRANSFER FORM—LEASED MATERIAL

| 1. Transfer Series: A. _____ (From) | B. _____ (To) | C. _____ (Number) |

2. Shipped by (Shipper):
Name _____
Address _____

3. Shipped to (Receiver):
Name _____
Address _____

4. Shipped for Account of: Lic. No.
Name
Address
Lease No.

5. Shipped to Account of: Lic. No. _____
Name _____
Address _____

Lease No. _____ Order No. _____

6. (For AEC Use Only):
Nuclear Material Draft (Form AEC-437)
Number

8. Material Description:

7. SS Material (Check One):
(A) Enriched Uranium ( )
(B) Uranium-233 ( )
(C) Plutonium ( )
(D) Other _____ ( )

9. This Transfer Involves:
(A) Initiating lease responsibility ( )
(B) Transfer of lease responsibility ( )
(C) Return to AEC for credit ( )
(D) No change in lease responsibility ( )
(Transfer of material only)

10. Material Quantities: A. Weight Units _____

B. Container No.	C. Piece Count	D. Gross Weight	E. Tare Weight	F. Net Weight	G. Element Weight	H. Weight % Isotope	I. Isotope Weight
Totals							

11. The Items and Quantities Listed Above Were Shipped

On _____, 19____

(Shipper's Signature)

12. The Items and Quantities Listed Above Were Received

On _____, 19____

(Receiver's Signature)

10-70801-3

UNITED STATES ATOMIC ENERGY COMMISSION TRANSFER FORM 388

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FIGURE 12

It is necessary that such material be stored away from other buildings and the amount of material stored be held to a minimum because spontaneous combustion may occur. Fire damage would be minimized and other buildings would not be exposed. A secured or outside storage area is recommended. To minimize the quantity of the pyrophoric uranium being stored, this type of material is periodically burned to form the oxide. The fire hazard is then completely eliminated. To facilitate handling, uranium scrap is segregated according to the following categories:

(1) solids

(2) chips

(3) oxides

(4) sludge

(5) contaminated non-soluble liquids

(6) contaminated non-burnable waste

Records Management

Purpose. Regulation 10 CFR 40, paragraph 40.61, "Records", requires that licensees shall keep records showing the receipt, transfer, export, and disposal of source material (uranium or thorium). Procedures for the control and accountability of uranium have been established based on regulations contained in the AEC Manual, Part 7400. An SS* Accountability Office shall be established as a central control over the flow of uranium both to and from a station and between Balance Areas within a station. It will maintain an inventory of material on hand which can be utilized to satisfy any reporting requirements. Internal forms and recording devices have been originated and incorporated with existing AEC Forms to establish both a system of control and a source of reports. The entire system is operated under the guidance of the SS Accountability Officer who has the prime responsibility for accounting for all uranium material.

Internal Controls and Transfers.

(1) A number of segregated Material Balance areas have been established based on processing, manufacturing, shipping and storage requirements, each area having a designated Responsible Officer (and alternates if necessary) who is responsible for the uranium under his control. These individual areas combine to comprise the entire accountability operation under the over-all supervision of the SS Accountability Officer.

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* Source and Special Nuclear Materials

(2) The responsible officers of the Material Balance Areas are the only personnel authorized to receive and transfer uranium in their particular areas, using a prescribed Transfer Form in quadruplicate (See Figure 13), copies ot which are provided the sender, receiver, and the SS Accountability Office. This transfer form is originated, signed and distributed by the sender, and after being verified as to material weights, is signed by the receiver.

(3) This responsible officer also maintains a running inventory over uranium under his control, conducts a physical inventory of uranium in his area each month, and submits a monthly report (See Figure 14) to the SS Accountability Office. This report becomes a part of the over-all inventory of the Arsenal and reflects the daily transferes in and out of the appropriate Material Balance Area. It reveals operational losses, other non-recoverable losses (called book physical inventory differences), and final physical inventory figures and includes any other comments deemed pertinent to the entire uranium control system. For weighing operations, all Material Balance Areas use the same standard type scale reading to the ounce, and the scales are tested every six months or whenever discrepancies are found.

Control Records.

(1) The SS Accountability Office is the central control office and contains the files, ledgers, transfer documents, monthly reports and all data pertaining to accountability inventory. This office receives a copy of all transaction documents (external and internal) and by utilizing these, and monthly reports from the Material Balance Areas, it maintains an inventory control for the entire accountability operation. The SS Accountability Officer uses the information contained in this office to ascertain the reasonableness of declared losses and to keep abreast of all accountability requirements.

(2) An Inventory Control Account Ledger (See Figure 15), using standard general sheets, is used to record the amount of uranium in inventory and to record all withdrawals and acquisitions of additional material. All incoming and outgoing shipments between the installation and outside facilities are made only by the SS Accountability Officer and recorded in a section of this ledger from copies of Property Turn-In Slips and any Shipping Documents which are the instruments used for such transactions. Uranium is issued to the various Material Balance Areas by the SS Accountability Officer on a regular internal transfer form. The Account Ledger also contains a section for each of the Balance Areas (See Figure 16) and all transfers are recorded here and used to check the accuracy of the Monthly Reports. All records are maintained to the nearest pound.

Control of Losses. The SS Accountability Officer issues uranium material only to responsible officers in the various balance areas. They, in turn, transfer uranium only to other responsible officers or the SS Accountability Officer. Responsible officers must take a physical inventory on the last working day of each month and report their account to the

ORDBE FORM 1278
24 OCT 60(REV)

URANIUM TRANSFER/ISSUE RECORD

TYPE U.: _____

VOUCHER NO.: _____

FORM (SIZE & NO.): _____

DATE: _____

IDENTIFICATION NO.: _____

AVERAGE COMPOSITION: _____

SECURITY CLASSIFICATION _____

FROM: _____

WEIGHT (IN LBS TO 10THS)

ORG.: _____ BLDG. NO. _____

TOTAL MATERIAL WT.: _____

TO : _____

% U. CONTENT: _____

ORG.: _____ BLDG. NO. _____

NET U. WT.: _____

SENT BY: _____

RECEIVED BY: _____

(RESPONSIBLE OFFICER OR ALTERNATE)

(RESPONSIBLE OFFICER OR ALTERNATE)

DISTRIBUTION (RESPONSIBILITY OF RECEIVER)

WHITE - RETURN TO SENDER   PINK - SEND TO WAL ACCOUNTABILITY RECORDER

YELLOW - RETAINED BY RECEIVER   GREEN - RETAINED BY SENDER UNTIL SIGNED WHITE COPY RETURNED

WATERTOWN ARSENAL URANIUM TRANSFER/ISSUE FORM

ORDNANCE FORM 1329
1 NOV 60 (REV)

URANIUM ACCOUNTABILITY RECORD
(FEEDER FOR A.E.C. RECORD 741B)

ORGANIZATION _____

MONTH _____ YEAR _____

DATE	COMMENT		1 TRANSFERS IN	2 TRANSFERS OUT	3 KNOWN LOSSES

END OF MONTH TOTALS

A. OPENING INVENTORY
(FROM PREVIOUS MONTH'S REPORT)

B. TOTAL AVAILABLE DURING MONTH
(COL. 1 PLUS A.)

C. TRANSFERS OUT (COL. 2)

D. BALANCE (LINE B - LINE C)

E. CLOSING PHYSICAL INVENTORY
(ITEM I)

F. NON-RECOVERABLE LOSSES
(LINE D - LINE E)

INVENTORY AND LOSSES

I. CLOSING PHYSICAL INVENTORY

A. IN STOCK _____

B. IN PROGRESS _____

C. FINISHED PARTS _____

D. RECOVERABLE SCRAP
(CHIPS ON HAND) _____

II. NON-RECOVERABLE LOSSES: EST.   BY DIFFERENCE

A. MELTING _____

B. FORGING _____

C. MACHINING _____

D. OTHER * _____

TOTAL

* EXPLAIN (i.e. MIXED WITH SAND, BURNED, ETC.):

SIGNED _____
(RESPONSIBLE OFFICER OR ALTERNATE)   DATE _____

WATERTOWN ARSENAL URANIUM ACCOUNTABILITY RECORD FORM

FIGURE 15 99 66

Material: D-38

Comments

WATERTOWN ARSENAL GENERAL LEDGER

UNITS: Weight in lbs. to the 10th of lb.

Date	Beginning Inventory	Receipts	Shipments	App'd Inv. Write-offs	*Bk-PIDs	Book Balance	Monthly Phys. Inv.

*Book Physical Inventory Differences

WATERTOWN ARSENAL INVENTORY ACCOUNT LEDGER

FIGURE 16

WATERTOWN ARSENAL ACCOUNT LEDGER

Balance Area Inventory Control

Organization: _____
Responsible Officer: _____

Material: D-38   Units: Weight in lbs. to the 10th of lb.

Comment	Date	Receipts	Transfers	D-Exp'ge*	Ending Inventory

*Book Physical Inventory Differences

Balance Area Inventory Control

Organization: _____
Responsible Officer: _____

Material: D-38   Units: Weight in lbs. to the 10th of lb.

Comment	Date	Receipts	Transfers	B-FID's*	Ending Inventory

*Book Physical Inventory Differences

SS Accountability Office. Any discrepancy between the physical and book inventory must be checked, and the differences reconciled. At the first indication of a "mysterious" loss, it must be reported to the SS Accountability Officer. Book Physical Inventory Differences (BPIDS) must be explained and documented on the monthly report. Spot checking of various material balance areas is conducted by the SS Accountability Officer to insure compliance with the program.

CHAPTER V

HEALTH PHYSICS AND SAFETY

Section 1 - Health Physics

Introduction

A properly organized and administered Health Physics program is essential in any operation involving uranium. The program must provide a working capability for all processing operations. The Health Physics staff should perform liaison between management and production personnel. It also should perform service functions such as the evaluation of radiological and toxicological hazards.

Uranium is not a dangerous radiological hazard, but in handling it, it is possible to exceed the very low exposure doses established as safe limits by the United States Atomic Energy Commission, the Federal Radiation Council, and the Surgeon General. Furthermore, since uranium is mildly radioactive, widespread contamination of facilities can result from careless handling. It is necessary to adhere to careful controls to avoid raising the background level of radiation that would otherwise result.

Various federal, state and private health physics laboratories have cooperated in investigating the many facets of health protection for personnel working with uranium. This work will continue until all epidemiological hazards, both short term and long term, are known.

The following paragraphs outline the requirements of health physics as currently practiced. It is felt that these afford the necessary coordination of all phases of a uranium processing program.

Maximum Allowable Concentrations

Maximum Allowable Concentrations for Air (Occupational). The maximum allowable concentrations for air-borne uranium dust are given in Table XXI. The maximum allowable concentration is a guide to the upper limit above which the health of personnel in the area becomes potentially endangered and where properly designed exhaust ventilation becomes necessary. If the air-borne concentration is well below the acceptable health limits, exhaust ventilation is not quite as necessary.

Maximum Allowable Concentration for Air (Environmental or Non-Occupational).

(1) As a rule, the maximum allowable concentration for air-borne uranium dust which may be discharged to the environment is one-tenth that which is allowed in the plant.

TABLE XXI

MAXIMUM ALLOWABLE OCCUPATIONAL CONCENTRATION
(NATURAL OR DEPLETED URANIUM*)

	Microcuries Per Milliliter ($\mu c/ml$)	Micrograms Per Cubic Meter ($\mu g/m^3$)
Soluble	7×10^{-11}	250
Insoluble	1×10^{-10}	357

* Above natural background

TABLE XXII

MAXIMUM ALLOWABLE ENVIRONMENT CONCENTRATION
(NATURAL OR DEPLETED URANIUM*)

	Microcuries Per Milliliter ($\mu c/ml$)	Micrograms Per Cubic Meter ($\mu g/m^3$)
Soluble	7×10^{-12}	25
Insoluble	1×10^{-11}	36

* Above natural background

(2) To determine the uranium dust content of exhaust air, the air is sampled by passing it through a filter paper held in a probe connected to a vacuum line. The filter paper is analyzed chemically or counted to determine its radioactivity. The technique used is quite critical and involves the matching of sampling velocity with duct velocity in order that representative samples of all particle sizes are captured by the probe and subsequently deposited on the filter paper. If this procedure is not used, truly representative samples will not be taken and errors will result when evaluating the stack effluent.

(3) The values of the maximum allowable concentration for air-borne uranium dust in a non-occupational environment are given in Table XXII.

Maximum Permissible Exposure (Dosage)

General. The maximum permissible exposure to personnel working in a radiation area is defined in AEC regulations Title 10 Code of Federal Regulations Part 20, "Standards for Protection Against Radiation." The limits are to be used as a guide and not to be considered as amounts which a man may normally receive. Any unnecessary exposure to radiation should be avoided. However, this is not to say that a man should not work with radioactive materials or with other sources of ionizing radiation, provided efforts are made to keep the exposure at a minimum.

Maximum permissible exposure to external radiation expressed in rems* per calendar quarter is as follows:

(1) Whole Body; head and trunk active
blood-forming organs; lens of eyes;
gonads- -1-1/4 rems/quarter

(2) Hands and forearms; feet and ankles - - - - 18-3/4 rems/quarter

(3) Skin of whole body- - - - - - - - - - - - - -7-1/2 rems/quarter

Weekly values expressed in millirems (mrem) for maintaining exposure within the maximum permissible value are as follows:

(1) Whole body; head and trunk active
blood-forming organs; lens of eyes;
or gonads- -100 mrem/week

- -

* The rem (roentgen equivalent man) is the quantity of any radiation imparted to a biological system (cell, tissue, organ, or organism) per gram of living matter by the ionizing particles present in the region of interest. The rem has the same biological effectiveness as an absorbed dose of one rad from lightly filtered X-rays generated at potentials of 200 to 300 kilovolts. Dose records are usually given in millirem (mrem) units. The rad is a unit of absorbed dose. One rad is equal to 100 ergs per gram.

(2) Hands and forearms; feet and ankles- - - - - - - 1500 mrem/week

(3) Skin- 600 mrem/week

These values do not include that amount of radiation exposure doses received by an individual from medical X-rays. A worker may be permitted to receive a nominal amount of medical X-rays while still receiving one-hundred millirem per week at work. A nominal amount would constitue routine diagnostic X-rays of the chest, limbs, extremities, head, etc. However, therapeutic X-rays sometimes amount to quite extensive dosages and when experienced, the advice of the health physicist and medical officer should be sought as to the advisability of continued work in a radiation area.

Uranium Dosage. Normal and depleted uranium both emit all three of the common forms of radioactive particles and rays (alpha, beta, and gamma). However, the alpha particles are of low penetrating power and are not a prime consideration in the whole body exposure of personnel. The major portion of the whole body exposure is from the beta radiation which is associated with the daughter products UX_1 and UX_2 (Thorium-234 and Protactinium-234). Table XXIII describes the contributory factors of the radiation from uranium. An individual would have to be exposed to considerable amounts and be in close proximity to the material in order to receive the maximum allowable weekly exposure dosage. Experience has shown that it is extremely unusual for an individual engaged in uranium fabrication to receive more than seventy-five millirem per month. Personnel average about thirty millirem per month, or approximately eight percent of the allowable dosage. Not included in this group are the uranium foundry workers who meet a different set of circumstances. When uranium is melted or alloyed, there is a migration of UX_1 and UX_2 to the surface of the melt thereby causing a concentration of these two highly radioactive isotopes. The dose rates exhibited are much higher than that of unmelted uranium.

Film Badges

Personnel working in radiation areas are required to wear film badges which consist of a piece of masked radiographic film inclosed in a holder. The amount of radiation exposure can be checked by determining the degree of film darkening after development. Processing of the film for Army installations is performed by Lexington Signal Depot, Lexington, Kentucky. The film pack is provided with two films and has a useful range of from fifty milliroentgens to one-thousand roentgens (50mr to 1000r).

When not being worn by personnel, the badges are kept in clean non-radiation areas. In uranium melting areas, the badges are worn encased in a plastic bag to avoid contamination by radioactive dusts. If the badge were contaminated, it would continue to be exposed to radiation while it is not being worn, exposing the film and giving a false indication of dosage.

TABLE XXIII

URANIUM SURFACE DOSAGE*+

Isotope	Energy	Contributing Radiation
$_{91}Pa^{234}$ (UX$_1$)	2.32 Mev	263 mrem/hr
$_{90}Th^{234}$ (UX$_2$)	0.1 and 0.2 Mev	20 mrem/hr
Gamma-daughter Products		2.7 mrem/hr
		263 mrem/hr

* All measurements were from a bare slab of uranium metal

\+ AEC Report No. AECD-2753 (NYOO-57)

Air Sampling

For purposes of air sampling, consideration is given to the particle size because some particles are small enough to be breathed in and out again without being retained by the body while others are too large and do not reach the lungs. The United States Public Health Service has established ten microns as the approximate size below which particles are respirable and accepted by the body. Particles larger than 10 microns are rejected by the nose and larynx.

To duplicate human retention curves (See Figure 17) more closely, two stage air samplers are used. This type of sampler differentiates between sizes of particles by utilizing a miniature "cyclone" collecting system (See Figure 18). Samplers are powered either by a paint spray blower or by a vacuum cleaner blower. In the paint spray type, air is measured in terms of liters per minute and in the vacuum cleaner type air is measured in cubic meters per minute. An adjustable flow rate meter is located on the suction side of these blowers and filter holders for both round and rectangular filter papers are provided. Only those particles that are acceptable to the body, i.e. less than ten microns, are considered characteristic of the air which an individual breathes and it is this portion of the particles collected on a filter paper that are subsequently evaluated by counting techniques.

It is well to note that this sampling method does not distinguish between the soluble and the insoluble particles of uranium. Both are potentially hazardous. The insoluble compounds may be retained in a persons lower respiratory tract and the soluble compounds may be rapidly taken into the blood through the lungs. Thus, the maximum allowable concentration for soluble uranium is based on chemical as well as radiological considerations and, for insoluble uranium, is based only on the radiological aspect.

In undertaking air sampling, consideration is also given to the face velocity of the particles across the filter paper of the sampler. This is especially important, if the human retention curve for particles of different sizes shown in Figure 17 is to be utilized. If the face velocity is too high for a particular filter paper, a considerable portion of the respirable particles will pass through the filter paper and escape being detected and the reported concentrations would be erroneous. Choice of filter paper is based upon several factors; percent penetration, self-absorption coefficient for alpha particles, electrostatic properties of the paper, etc.

Laboratory Procedures

Air and smear samples are usually analyzed by physical means. Because the particles collected on the filter paper are radioactive, they may be counted using a low background internal or external (125 microgram cm^2 window) proportional counter in conjunction with a scaler and high voltage power supply (See Figure 19). The gross alpha activity is computed from the scaler read out and correction fractors such as background, self-absorption, back scattering, etc. Results are converted

1"STAGE COLLECTION
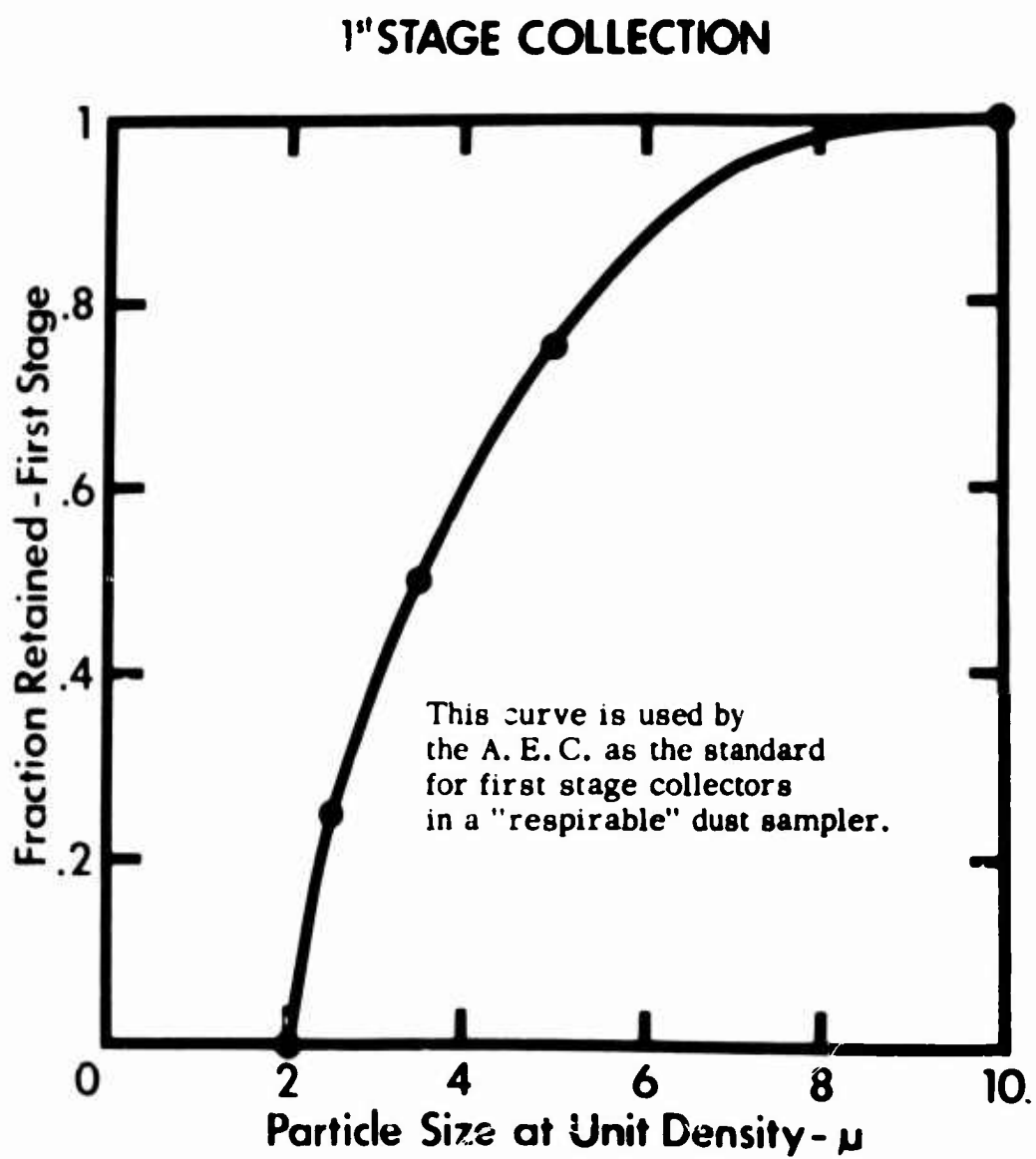
HUMAN RETENTION CURVE

FIGURE 17
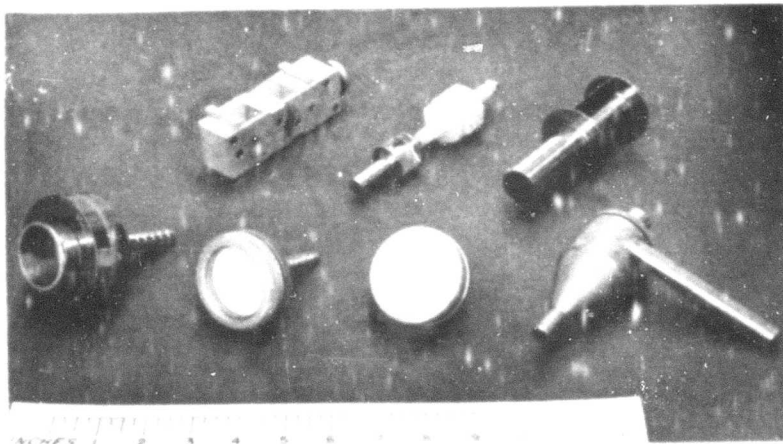
FILTER HOLDERS FOR AIR SAMPLERS
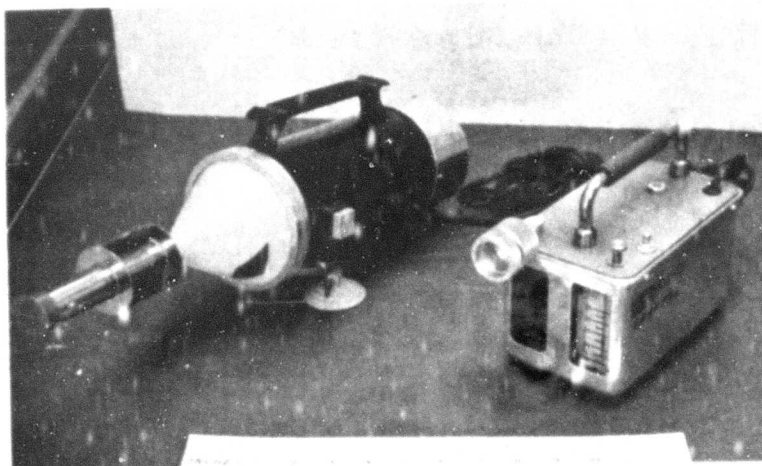
AIR SAMPLERS
ARMY MATERIALS RESEARCH AGENCY

FIGURE 18

PROPORTIONAL COUNTER SETUP
ARMY MATERIALS RESEARCH AGENCY

FIGURE 19

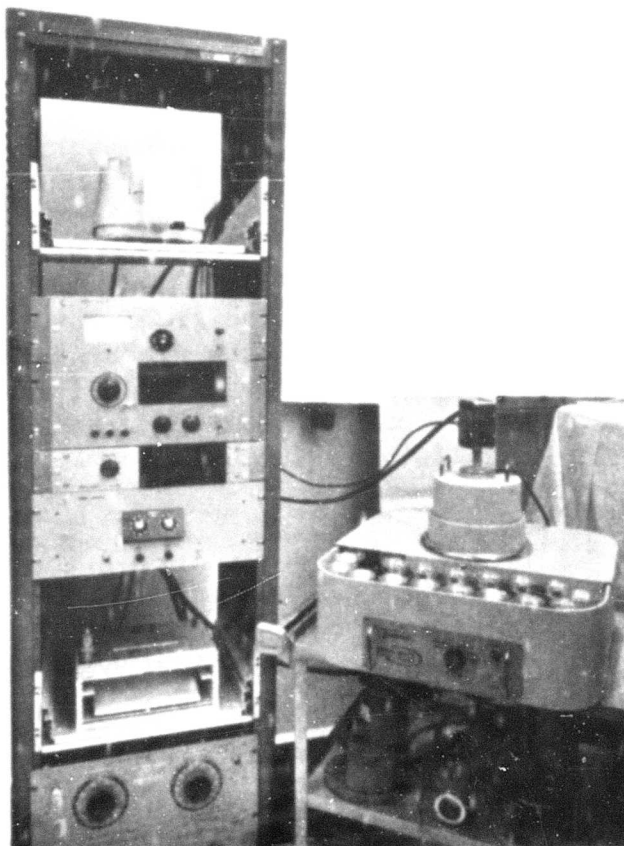from total disintegration per minute (dpm) per cubic meter of air (dpm/m^3) to microcuries per cubic meter of air $(\mu c/m^3)$.

Uranium Daughter Product Analysis $(Th^{234}$ and $Pr^{234})$. The daughter products collected in an air sample are evaluated by a gamma scintillation detector and crystal in conjunction with a spectrometer and scaler. The gross activity is computed from the scaler read out and correction factors such as background and crystal geometry. The results are expressed in microcuries per cubic meter of air per isotope $(\mu c/m^3)$.

Uranium Urine Analysis (Bio-assay). The uranium content of a urine sample is determined by the measurement of the fluorescence produced by the sample in a sodium fluoride (NaF) flux. The total weight of the uranium is measured fluorometrically on a microammeter and the amount calculated from this data. The results are expressed in microcuries per milliliter $(\mu c/ml)$.

Survey Instrument Calibration. Survey instruments (See Figure 20) used in the uranium areas are calibrated using the gamma rays from calibrated Cobalt 60 sources. Two points on each scale (high and low) are plotted. The equation used to compute the radiation dose rate at a fixed distance in free air space from the unshielded Cobalt 60 source is given below:

$$mr/hr = \frac{S' \times 13500}{d^2}$$

where

mr/hr = milliroentgens per hour
S' = millicuries of Cobalt 60 at time of calibration
d = distance from source in centimeters

Medical Supervision

General. Preplacement, annual, terminal, and special medical examinations are conducted by the medical officer. All personnel who are on the health physics roster are required to have physical examination yearly. Special medical examinations are given in the case of suspected or known overexposure, ingestion, or inhalation of radioactive materials.

Bioassay (urine values). The yearly examination may be considered as a complete general check-up to ascertain the workers over-all health. The only special test given is a bio-assay for the specific radio-nuclide that could have been inhaled or ingested. When personnel are exposed to normal or depleted uranium, a bio-assay is performed using a fluorometric technique sensitive to 10^{-3} gram U_3O_8 of urine. This test was formerly performed semi-annually but was changed to a yearly basis because of the low value of the results.
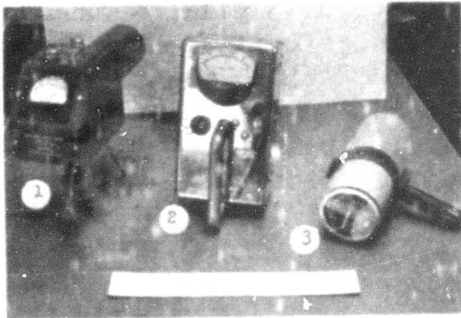
a. HIGH RANGE BETA AND GAMMA RADIATION METERS

   1. Range - .01 mr/hr to 10,000 r/hr
   2. Range - 0 to 5000 mr/hr
   3. Range - 0 to 1500 mr/hr
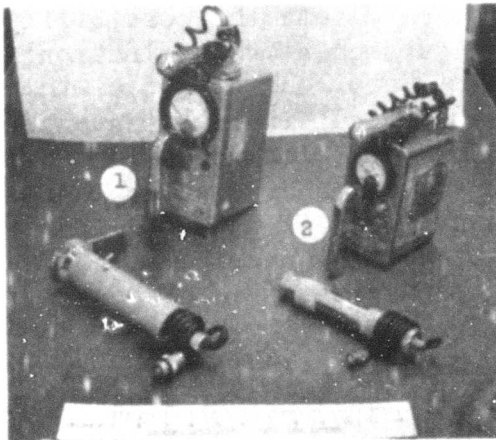
b. LOW RANGE BETA AND GAMMA RADIATION METERS

   1. Range - .01 to 200 mr/hr
   2. Range - .01 to 20 mr/hr

c. ALPHA RADIATION METERS

   1. Range - 0 to 2,000,000 counts/min
   2. Range - 0 to 10,000 disintegrations/min
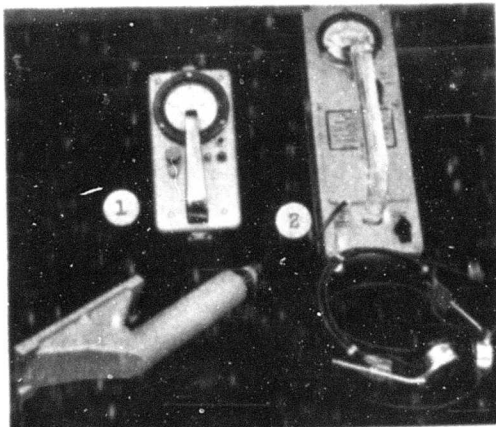
TYPICAL SURVEY METERS

FIGURE 20

Blood Counts. The general opinion was that personnel showing white cell counts of 12,000 or more or red cell counts of 3 million or less would not be permitted to work within radiation areas. It was generally believed that people possessing these shifts from "normal" blood counts were in some way more susceptible to small radiation dosages. Current knowledge has refuted these opinions and blood count criteria are not singly applied but rather only in consonance with the total medical picture of the individual.

Section 2 - Safety

Protective Apparel

General. Protective clothing is worn by all personnel working in uranium areas. The clothing is provided to eliminate the possibility of contaminating the workers own clothing and subsequent contamination of non-occupational areas. Both fire retardant paper and cotton clothing are used. The paper clothing is the more practical in some instances because of the elimination of laundering. However, cloth clothing is used especially in areas where there are materials which are easily ingited. Normal uranium is much more pyrophoric than alloys of depleted uranium with molybdenum. As more AEC licensed commercial laundries are established, consideration will be given to utilizing cloth protective garments more extensively.

All personnel provide their own shoes but must use protective covers which are stored at the entrance to the uranium area. Tests have shown that any material adhering to the shoes is rapidly worn off in walking between buildings but care must be exhibited to prevent contamination of low level counting laboratories, located throughout an installation. Contamination of the ground would not be a health hazard but would impose difficulties in sensitive work.

Exhaust Ventilation and Air Cleaning

To maintain the level of airborne particulate uranium below the in-plant maximum allowable concentration, all processing and machining operations should be provided with local exhaust ventilation. The degree or extent of ventilation varies with the nature, amount, and method of release of the contaminant. Consequently, no single method of control can be recommended. Effective control of airborne contamination, nevertheless, is predicated on good ventilation design. Exhaust systems, therefore, should always be designed by qualified ventilation engineers.

The theory of control depends upon the creation of an air flow past the point of release of the contamination causing the air and contamination to flow into an exhaust hood. The shape, position, size, and other design factors of an exhaust hood will depend on the specific operation to be ventilated. A common approach to the design of such hoods is to picture the operation as being totally enclosed and then to provide openings for

access and operation as required to perform the task. Openings should be kept to a minimum, both in number and in size and whenever possible positioned such that they are out of the natural path of release of the contaminant. Controlled air velocities through these openings should be maintained at 100 to 150 linear feet per minute per square foot of open area.

Exhaust systems for control of airborne uranium dusts are usually of the high volume, low pressure type. The system consists of the exhaust hood, the associated duct work, an air cleaning or filtering device and the exhaust fan. Each of these four sections of the system must be designed or selected to accomplish effective control.

Prior to release of the captured contamination to the outdoors, consideration must be given to the degree and type of air cleaning to be performed so as not to exceed permissible levels out-of-plant. Air cleaning devices fall generally into two groups: air filters and dust collectors both of which are useful in removal of captured uranium dust in exhaust systems. They may be used individually or in series depending upon the amount of dust or "dust loading" to be handled. For low dust loadings up to three or four grains per cubic foot, the air filter type is generally used. In operations involving heavier loading, (e.g. 5 to 20 grains per cubic foot), the air cleaner is usually of the dust collector type.

Selection of the air cleaning equipment will include factors such as:

(1) Concentration and particle size of the contaminant.

(2) Degree of collection or cleaning required (collection efficiency).

(3) Characteristics of the air or gas stream (temperature, water vapor content, air volume, etc.).

(4) Characteristics of the contaminant (specific gravity, wettability, abrasiveness, etc.).

(5) Method of disposal of the collected material.

The most important factor from a health and safety point of view is the degree of collection required or the collecting efficiency of the air cleaning device. Because the exhaust system finally discharges the control air to the outdoors, it is of extreme importance that this discharge itself not become a source of out-of-plant or community contamination. The degree of collection will depend to some extent upon plant or site location, i.e. its proximity to other industrial or residential buildings. Consideration must be given to local municipal and state air pollution codes and ordinances in addition to USAEC permissible limits. Most commercial industrial-type air cleaning equipment does not achieve the degree of collection required to meet the USAEC limits for out-of-plant airborne uranium. This is due mainly to an inability to capture the extremely fine particles, i.e. particles below 1 micron diameter. Experience has shown that to achieve

these limits, primary filtration on dust collecting equipment usually must be followed by secondary filters possessing a high filtration efficiency for fine particles.

These filters can be of the so-called 85, 95 or 99.9+ percent efficiency type. Several manufacturers now market these filters under various trade names. The percents usually refer to their collecting efficiency for particles of 0.3 microns diameter. Selection will be based upon process, health aspects, plant location and permissible limits. Evaluation of the total system is accomplished by sampling the operations and the discharge air with subsequent analysis by counting or chemical techniques.

Decontamination

Equipment. All tools and equipment used are decontaminated by standard degreasing techniques. Those items which are difficult to decontaminate are sent to the health physics laboratory and are placed in an ultrasonic cleaning bath. This method has been most effective. Tools are decontaminated when they are to be transferred to a non-radiation area. Snift supervisors have the responsibility of checking all tools before they are transferred. Worn or broken tools that are not to be used again, or items which cannot be economically decontaminated, are disposed of by health physics personnel.

Personnel. Good personal hygiene is the main protection for personnel who work with uranium. Personnel are required to wash hands and face before leaving any radiation area. In the case of those personnel working with vacuum furnaces, a shower is required immediately after completing the job. Protective clothing is not allowed out of the radiation areas. Table XXIV lists personnel contamination limits.

Pyrophoricity of Uranium

Under certain conditions uranium is an extremely pyrophoric material similar to magnesium, titanium and zirconium. Though experiments have shown that it is extremely difficult to obtain the proper conditions for large pieces to ignite, there have been several instances reported of uranium stock ignited spontaneously. The main fire problem is with chips, shavings and turnings, which ignite readily and burn with an intense heat. The heat generated by a small pile of burning chips is intense enough to buckle a one-half inch steel plate suspended over the pile. Obviously, if such a material were allowed to burn uncontrolled within a building, severe damage would result.

Procedures for Fire Prevention.

(1) Fire regulations prohibit the accumulation of fine uranium scrap within a building. All such material is removed at the end of each shift and transferred to a segregated uranium storage area by fire department personnel. This area is usually located in an open field and surrounded by a chain link fence with suitable warning signs (See Figure 21).

TABLE XXIV

CONTAMINATION LIMITS

Surface	Activity	Max. Allowable Rate/100cm^2	Smear Limit in d/m* for 100 cm^2
Skin of body	alpha	150 d/m	30
	beta	0.1 mrem/hr	200
Hands+	alpha	150 d/m	30
	beta	0.3 mrem/hr	200
Personal Shoes (Outside)	alpha	300 d/m	30
	beta	0.6 mrem/hr	200
Issued Shoes (Outside)	alpha	300 d/m	30
	beta	2.5 mrem/hr	1000
Personal Clothing	alpha	100 d/m	
	beta	0.18 mrem/hr	
Issued Clothing	alpha	150 d/m	
	beta	2.75 mrem/hr	
Laboratory Areas, Tools	alpha	300 d/m	30
	beta	0.25 mrem/hr	200
Unrestricted Areas, Items to be sent to shops, etc.	alpha	300 d/m	30
	beta	0.05 mrem/hr	300

---

* d/m - disintegrations per minute

+ Surface area is considered 100 cm^2, except hands where the area considered is the entire hand.
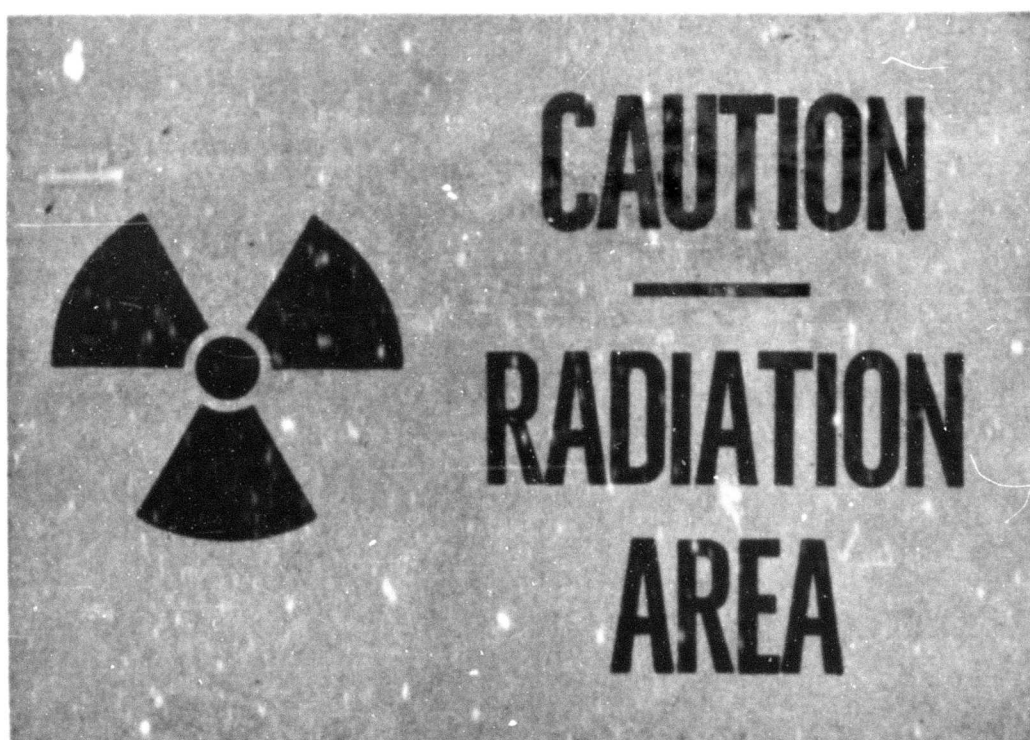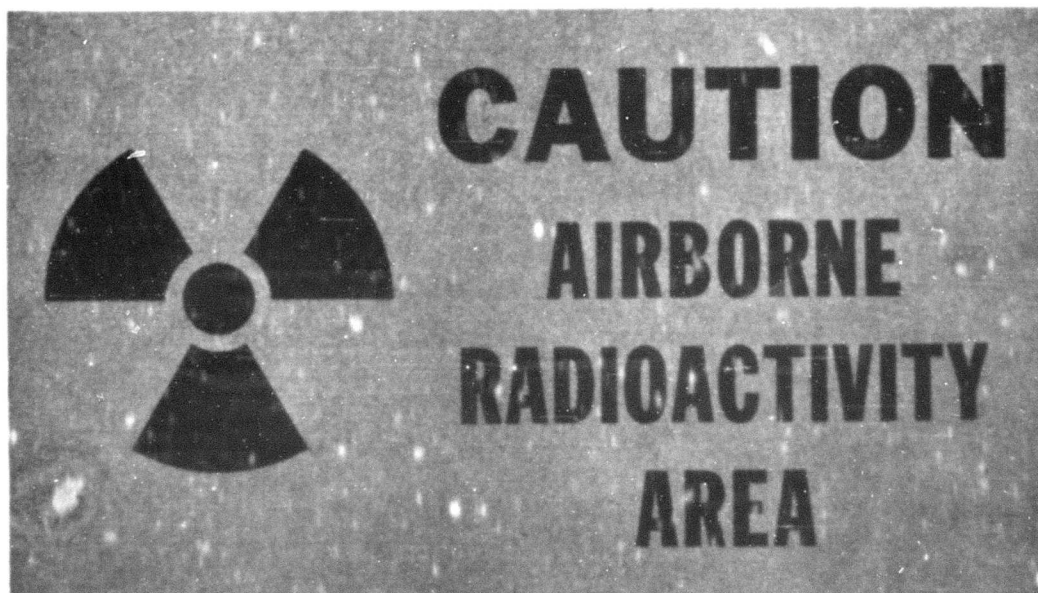
SAMPLE WARNING SIGNS

FIGURE 21

(2) To prevent local ignition in machining areas, extensive quantities of coolant are used. The machinists are instructed to keep chips and turnings submerged or wet with coolant while they are in the machine bed. Small fires which do start in lathe beds are easily extinguished with a "Metal-X" type powder and in many cases the machining operation is not interrupted.

(3) If fires start in scrap barrels inside a building, the nearest personnel apply Metal-X type powder and the barrel is then moved outside the building. The fire department completes the extinguishing of the fire with a fine spray of water. The water filled barrel will continue to bubble hydrogen gas for some time and must be watched closely as the hydrogen might reignite. If a fire starts in an outside storage area, the barrel is segregated from the main area and allowed to burn itself out under the surveillance of the fire department.

Factors Affecting Uranium Fires. The conditions necessary for spontaneous or unpredictable ingition of uranium are not fully known. The significant factors influencing the character of a uranium fire are listed below:

(1) The inherent reactivity of the active substance and the heat released per volume of reacting material.

(2) The specific area of the reacting particles.

(3) The physical and chemical coupling among the reacting particles.

(4) Subsidiary heat producing reactions, such as the combustion of hydrogen.

(5) The cooling and oxidizing potentials of the environment.

Waste Disposal

Uranium waste generated in various machining and fabrication areas is shipped to a segregated storage area within the installation for disposition. It is the responsibility of all supervisors of radiation areas to see to it that this type of material is not allowed to accumulate and cause contamination problems or fire hazards.

The waste scrap is burned periodically in an open trough type incinerator. An ordinary match is sufficient to ignite the material. After the material has completely burned to an oxide and been allowed to cool, the residue (oxide) is shovelled into an approved thirty-gallon steel drum. When the drum is full, it is sealed and shipped to Oak Ridge, Tenn. for burial under the guidance of the SS Accountability Officer. Uranium scrap will not be accepted at Oak Ridge if it is in a potentially pyrophoric state.

Although the burning operation itself is safe when performed as pre-
scribed, the shovelling and packaging of the residue is potentially hazar-
dous because of possible inhalation of particulate matter by personnel.
Protective clothing and respirators are provided to all personnel involved
in handling of the oxides.

Small dumpster-type containers may also be used as incinerators for
uranium scrap. Newly arrived scrap is burned on top of residue from prior
scrap fires until the container is filled with residue. A steel cover is
then welded on the dumpster and it is shipped for burial. This method of
disposal eliminates the potentially hazardous shovelling operation and re-
duces the number of handling operations.

The exteriors of all containers are checked for removable contamina-
tion by wipe testing. The limits for fixed and removable contamination are
specified in Watertown Arsenal Manual of Administration 2-700001 Sec. 12.2.
Whatman 41 filter paper is wiped over a 100 cm^2 area and a wipe analysis
is performed at the health physics laboratory. After the containers are
wipe tested and the results evaluated, the barrels are labeled and prepared
for shipping in accordance with AEC and ICC regulations (See Figure 22).
Record of all radioactive waste disposal is maintained by the Health Physics
Branch in accordance with the 10 CFR 20.

Transportation

General.

(1) Depleted uranium metal is a Class D Poison, Group I or Group II,
as defined in paragraph 73, 391, T. C. George's Tariff 13 and Title 49,
Parts 71 to 78, Code of Regulations, and must be packaged, marked, and
labeled accordingly.

(2) If a government vehicle is used to transport this material,
Municipal, State, or Federal Regulations and restrictions imposed by the
various Army Area Commanders must be complied with.

Transportation of uranium component parts assembled into an item
which possesses a greater hazard, (e.g., ammunition containing explosive
material) must meet the requirements of the ICC for packaging, marking,
labeling, and handling as provided for items into which the depleted
uranium component is assembled, in accordance with Title 49, Parts 71 to
78, of the Code of Federal Regulations.

Air Transportation. Transportation by passenger air cargo aircraft
is regulated by T. C. George's Tariff 13 and Title 49, Parts 71 to 78,
Codes of Federal Regulations. Regulations more specifically applicable to
air transportation are contained in Civil Aeronautics Manual Part 49 and
Appendix A, B, and C "Transportation of Explosives and Dangerous Articles".

HANDLE CAREFULLY

RADIOACTIVE MATERIAL

CLASS-D POISON   Group I or II

No person shall remain within 3 feet of this container unnecessarily

Do not place undeveloped film within 15 feet of this container

Principal radioactive content _____

Activity of contents _____

Radiation units from package No. _____

Not more than 40 units shall be loaded in one car or one
motor vehicle or held at one location

This is to certify that the contents of this package are properly
described by name and are packed and marked and are
in proper condition for transportation according
to the regulations prescribed by the Inter-
state Commerce Commission.

Shipper's name required
hereon for ship-
ments by
EXPRESS

This is to certify that the
above named articles are properly
described, and are packed and
marked and in proper condition
for transportation according to
the regulations prescribed by
the I.C.C.

date_____   name:_____
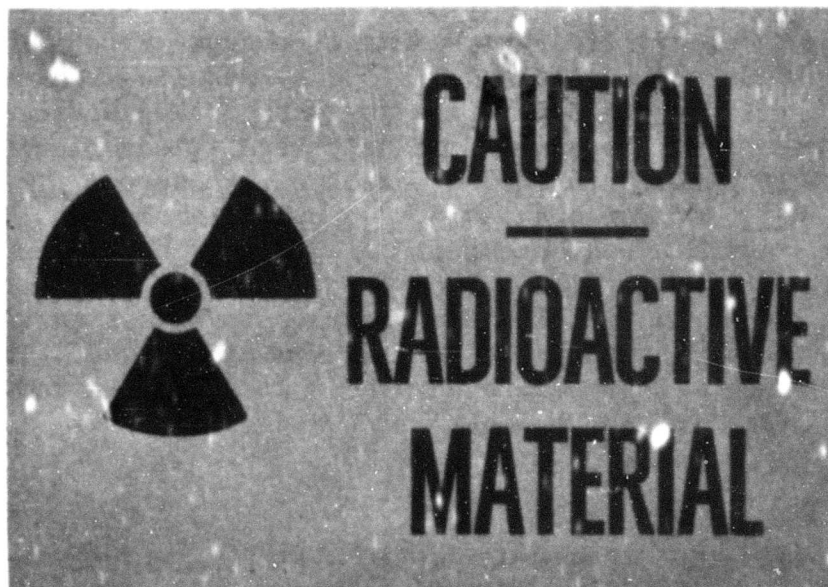
URANIUM SHIPPING LABELS

FIGURE 22, a b & c

First Aid

All wounds, whether lacerations, abrasions, or ulcerations occuring while working with uranium, are treated by conventional medical techniques. It is good practice to wash out any wound until it is free of foreign matter. Consequently, it is safely assumed that any uranium which might contaminate the wound would be cleaned out. The discretion of the medical officer as to whether a wound is free of radioactive material is relied upon. The health physicist might be called upon to check the wound with an end-window probe that is extremely sensitive to small amounts of uranium.

In the case of suspected internal overexposure, the individual should be dealt with in accordance with AR 40-582.

First aid kits are not provided in the areas, as it is felt that better medical attention can be obtained at a dispensary, under the supervision of the medical officer and qualified industrial nurses.

Surface Preparation (Health Hazards)

In the cleaning of uranium metal surfaces, dilute nitric acid (6N) is commonly used as a reagent. Caution must be practiced to prevent the use of more concentrated mixtures because nitric acid and uranium may react with explosive violence. This is especially true of chips and turnings. If uranium is to be disolved in dilute nitric acid in quantities greater than 5 grams, then it must be added to the acid a little at a time.

Section 3 - Record Management

General

An accurate, current, record management program is required to provide the necessary data on exposure dosage, bioassay results, radiation survey instrument calibration and repair, wipe tests on sealed sources, and radiation source inventories. Department of Army regulations require but one form (DD Form 1141) be used to record personnel exposures. The USAEC utilizes two forms: AEC Forms 4 and 5. "Occupational External Radiation Exposure History" and "Current Occupational External Radiation Exposure".

Watertown Arsenal has developed a record-keeping system which is a modification of the Remington Rand "Kardex" Visible System. The system has three categories: (1) A Health Physics Roster, (2) an isotope record system, and (3) Radiation Survey Instrument Records.

Health Physics Roster

This roster is composed of two cards, a personal history card (See Figure 23) which includes the individuals medical history, and a yearly exposure index (See Figure 24). Changes or additions to the roster are made using the form shown in Figure 25.

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FIGURE 23

HEALTH PHYSICS ROSTER

HEALTH PHYSICS ROSTER

Name _____ M ☐ F ☐ Film Badge No. _____

Birth Date _____ Education Elem. ☐ H.S. ☐ Coll. ☐ P.G. ☐ PR No. _____

Organization _____ Branch _____ HP Educ. _____

Supervisor _____ Tel. Ext. _____ Job Title _____

Building No. _____ Room No. _____ Interview Date _____

(Exposure Area) From _____ To _____ Exposure History

Date _____

Head
Teeth
Abdomen
Chest
Limbs
Somatic
Other

Yearly Dose	Unit-Rem	(W) Whole Body		(E) Extremities	
Year	Total (W)	Total (E)	Year	Total (W)	Total (E)
19			19		
19			19		
19			19		

Notes:

(Occupational)

ORDBE FORM 397
4 May 1961

YEARLY EXPOSURE INDEX

Name _____ P R Number

Film Badge No.	Code Period	Date		Exposure Record				P R Number	Bio-assay	
		From	To	Body Dose	Res Cum	Wrist Dose	Res Cum	Ion	Date	Conc

ORDBE FORM 500
3 SEP 58 (REV)

REQUEST FOR CHANGE
HEALTH PHYSICS ROSTER WATERTOWN ARSENAL
(Submit in Triplicate)

To: Health Physicist   Date _____

From:

1. It is requested that the following actions be recorded on the Health Physics Roster:

   Add to Roster   ☐   Change Part I: Form ORDBE 500   ☐   ☐

   Remove from Roster   ☐   Add to Radiation Exposure Record ☐   ☐

Name: _____ Payroll No. _____ Extension _____

Job Description _____

_____

_____

Pre-employment physical _____ Location _____ Educational Level
                              Date

Terminal physical _____ Organization _____ Grammar School ☐
                              Date

                                             Branch _____ High School ☐

                                             Bldg. No. _____ College ☐

Radiation exposure record (include all medical and dental X-Ray and previous occupational exposure)

2. Justification or explanation:

                              Supervisor's Signature _____ Ext. _____

_____

(To be filled out by Health Physics Office)

To: Post Dispensary

   Initiate Health Physics Folder for above employee

Film Badge No. _____ Neutron Badge No. _____ Dosimeter No. _____

BP phys. exam. _____ Per phys exam. _____

Bioassay _____ Blood Test _____ X-Ray _____

Remarks: _____

_____

_____

_____

                                    APPROVED:

                                    _____ _____
                                    Health Physicist   Date

                                    _____ _____
                                    Medical Officer   Date

REQUEST FOR CHANGE - HEALTH PHYSICS ROSTER

The personal history card includes such information as yearly exposure, medical X-ray record, education, exposure areas in which the individual has worked, etc.

The prescribed military and AEC forms do not readily lend themselves to a quick check of an individual's exposure record as it would be necessary to check through each medical history folder separately. Furthermore, it would be difficult to note any correlation between two or more individuals' exposure. This correlation is especially useful where control of personnel exposure in a particular area is in question. For example, if two uranium foundry workers were receiving similar exposures from one film badge period to another, one might investigate their method of operation and take the necessary measures to correct the situation.

The yearly exposure card is provided with a colored sliding index of the individuals current total exposure. This card lists film badge number, exposure for the period during which the badge was worn, and total exposure to date. All cards are grouped by work areas to provide a cross reference of one individual to another. Any exposure noted on either a wrist or ring film badge is also recorded on the card. Another section of the card includes an index of the individual's bioassay data.

Isotope Record Card

The isotope record card shown in Figure 26, contains the data necessary to maintain control of radioisotopes: data covering the use of the particular isotope, inventory, wipe test results, and waste disposal records. Also, the bottom of the card has an index containing the name, isotopic number, initial activity, and location of the isotope.

Radiation Survey Instrument Card

This card serves several purposes. It is used to inventory all survey instruments. On it is recorded calibration and maintenance data, make and model number, and tube and battery type of the survey instrument (See Figure 27).

ISOTOPE RECORD CARD

FIGURE 26

RADIATION INSTRUMENT REC'RD

Type   Mfg.   Model No.

Tube   Sr No.   Decal No.

Bar cries:

Notes:

	Calibration				Calibration		
Date	Source	Ref		Date	Source	Ref	

Maintenance and Repair

Type

Type

Location

RADIATION SURVEY INSTRUMENT CARD

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